CANADIAN JOURNAL OF RESEARCH

VOLUME 14 SEPTEMBER, 1936 NUMBER 9

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OTTAWA, CANADA

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The Canadian Journal of Research is published by the National Research Council of Canada under authority of the Chairman of the Committee of the Privy Council on Scientific and Industrial Research. All correspondence should be addressed:

National Research Council, Ottawa, Canada

Canadian Journal of Research

Issued by THE NATIONAL RESEARCH COUNCIL OF CANADA

VOL. 14, SEC. C. SEPTEMBER, 1936 NUMBER 9

AGRICULTURAL METEOROLOGY: SOME CHARACTERISTICS OF PRECIPITATION IN SASKATCHEWAN AND ALBERTA[1]

BY J. W. HOPKINS[2]

Abstract

A five-year moving average of autumn and winter (Sept. 1 to March 31) and spring and summer (April 1 to Aug. 31) precipitation showed undoubted variation with time over the years 1898–1934, periods of above- and below-average moisture alternating, though not with simple periodicity. There were in addition large irregular annual variations in the amounts recorded at individual stations.

In spite of irregularities, to be expected in the limited sample of years available, the frequency distribution of seasonal precipitation at Edmonton, Calgary, Battleford and Swift Current showed no gross asymmetry, seasons with precipitation in the vicinity of the average being on the whole the more numerous. There were, however, qualitative differences in the frequency distribution of the annual amounts of rain in the five individual spring and summer months. Correlation studies revealed no consistent association between the amount of precipitation in different spring and summer months of the same year, or between the totals for the autumn and winter, and for the following spring and summer period.

The average (1916–1932) percentage of days on which rain fell showed a distinct seasonal trend during spring and summer, being lowest in April and highest in June. Similar variation was noted in the average amount of rain per rainy day, which was also lowest in April and highest in June and July. In all five months the frequency distribution of the daily amounts (exclusive of zero) was decidedly skew, the smaller amounts being much the more numerous. The proportion of the total precipitation received in small daily amounts was on the average much increased during periods of subnormal rainfall.

Although there was a significant correlation between the total precipitation at different stations in the same district during the same month, analyses of variance revealed that there was also considerable local variation in the four districts studied. The monthly amounts received in daily quantities exceeding 0.30 in. per day showed relatively even greater local variation than did the total precipitation. Consequently, the intensity of precipitation, as measured by the percentage of the monthly totals accruing from the larger daily falls, was also subject to appreciable local fluctuations.

Some agricultural implications of these aspects of the weather are indicated.

Introduction

In previous agricultural meteorological investigations (5–8) the author was able to demonstrate statistically significant correlations between annual variations in rainfall and temperature, and the yield and nitrogen content of wheat crops grown in central and southern Saskatchewan and Alberta. It is now desired to present the results of a study complementary to the foregoing, dealing quantitatively with some average characteristics of the seasonal precipitation in these districts, and also analyzing the fluctuations which

[1] *Manuscript received August 20, 1936.*

Contribution from the Division of Biology and Agriculture, National Research Laboratories, Ottawa. Published as Paper No. 100 of the Associate Committee on Grain Research of the National Research Council of Canada and the Dominion Department of Agriculture.

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past experience has shown to occur from year to year in the precipitation at a given place, and from place to place in the same district during a given year.

This aspect of the subject was touched upon in one of the earlier papers (5), when the seasonal trend, annual variation, and intra-annual correlation of precipitation at representative meteorological stations in the districts referred to were determined for the five spring and summer months, April to August, inclusive. The present communication deals with further details of the precipitation statistics of selected stations in these districts. Specifically, consideration is given to secular variations in annual precipitation, to the frequency of occurrence of different seasonal, monthly and daily totals, to the correlation between different monthly amounts in the same season, and to the intra-monthly variability from place to place in the same district.

As in the previous studies, the precipitation data used were those compiled by the Meteorological Service of Canada (15).

Annual Variation in Monthly and Seasonal Precipitation at Specified Points

For the study of temporal variations in precipitation, the following meteorological stations were selected:

Central Alberta: Edmonton, Lacombe.
Central Saskatchewan: Battleford, Saskatoon.
Southern Alberta: Calgary, Lethbridge.
Southern Saskatchewan: Indian Head, Swift Current.

Complete records of the precipitation by months during the 37-year period 1898 to 1934 were assembled for all of these excepting Lacombe and Saskatoon, which provided slightly shorter series.

Secular Trend

Attention was first directed to the total precipitation during successive crop years. This may be conveniently divided into an autumn and winter portion (September 1 to March 31) and a spring and summer portion (April 1 to August 31). Precipitation in both of these periods fluctuated markedly from year to year at all eight stations. The situation obtaining is exemplified in Figs. 1 and 2, constructed from the observations at Calgary and Lethbridge.

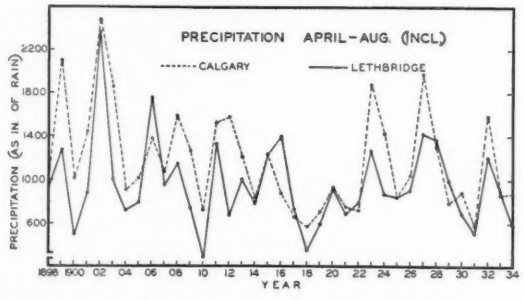

FIG. 1. *Annual variation in spring and summer (April 1 to Aug. 31) precipitation at Calgary and Lethbridge, Alberta, 1898–1934.*

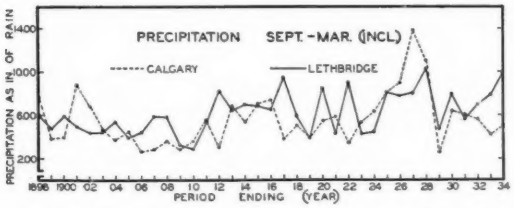

FIG. 2. *Annual variation in autumn and winter (Sept. 1 to March 31) precipitation at Calgary and Lethbridge, Alberta, 1898–1934.*

(In these and succeeding figures, precipitation, whenever occurring, is shown as "inches of rain", irrespective of whether it actually fell in the form of rain, snow or hail). As is well known, a major part of the total annual precipitation in the prairie provinces is usually received during the spring and summer months. This circumstance is clearly evident in the figures referred to; but it should also be noted that the April-August totals were correspondingly more variable than those for September-March.

Upon first examination, the annual amounts at the various stations showed little clear evidence of any definite secular trend. A dry season might be followed by another dry season, or by one of intermediate or above-average moisture. In order to bring out more clearly any temporal sequence underlying these irregular fluctuations, recourse was had to a simple process of smoothing the data for the two stations in each district. Precipitation during the same season at the two selected stations was first averaged; then the resulting seasonal means were smoothed by the calculation from them of successive values of a five-year moving average. The course of these averages is shown in Fig. 3.

Although there is still some irregular variation, the five-year averages of April-August precipitation (solid lines) show definite changes with time, now increasing to a maximum, then progressively declining until a minimum is reached, after which a further improvement takes place. Only the main features of this variation will be considered here, for in view of the pronounced local fluctuation in the incidence of precipitation, to be discussed below, observations at two stations alone cannot be expected to indicate accurately the amount received over any extensive area.

Even with this consideration in mind, it cannot be said that there is marked similarity in the course of the averages for any two of the four districts; nevertheless the movements of the smoothed values in three of them have certain features in common. On the average, summer precipitation was relatively abundant from 1900 until about 1911 at the two southern Saskatchewan stations and until 1913 at those in southern Alberta. At the central Alberta and Saskatchewan stations a dry period centred about 1907 was followed by an increase in the five-year average, which reached its maximum in 1910 and 1913, respectively. A progressive decline was then experienced in all districts, the low point of which was attained in 1916 at the southern

Saskatchewan stations, in 1917 at the central Saskatchewan ones, and not until 1919 at those in the two Alberta districts. Subsequently there was again a progressive improvement in the average, but in southern Alberta and in central and southern Saskatchewan this was once more followed by a decline, which appeared to be about its minimum at the termination of the

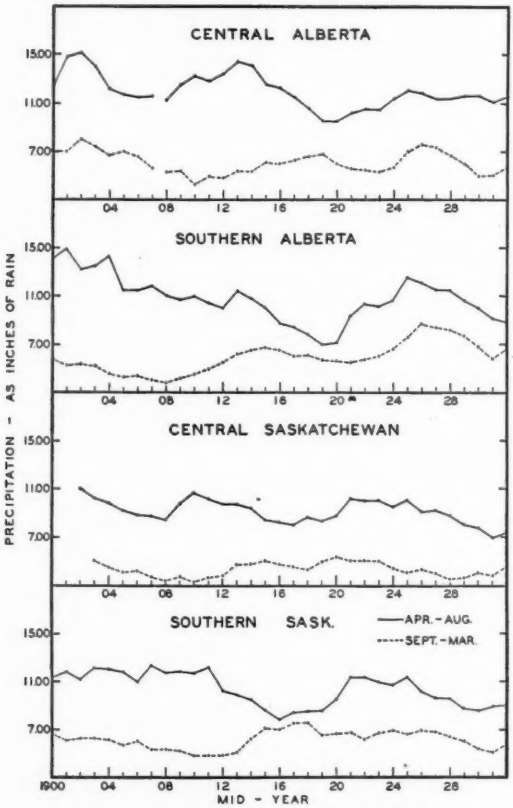

FIG. 3. *Five-year moving average of spring and summer (April 1 to Aug. 31) and autumn and winter (Sept. 1 to March 31) precipitation at meteorological stations in central and southern Saskatchewan and Alberta, 1898–1934.*

sequence. At Edmonton and Lacombe, the two central Alberta stations, this final decline did not occur, the general level of precipitation being well maintained from 1925 until 1932, the last available mid-point of the five-year average. This circumstance may lend some support to the view that although the greater part of the moisture falling in the summer rains in the prairie provinces is drawn from the Gulf of Mexico, the foothills, west-central and Peace River districts in Alberta may also receive moisture-bearing air from the northern Pacific Ocean.

It may perhaps be noted from Fig. 3 that in addition to these recurrent oscillations in the five-year average of April–August rain, there is also an apparent downward trend in the general level of the average. It seems probable, however, that this is not indicative of an actual modification of the climate in the direction of aridity, but is simply due to the fact that the commencement and termination of the series of annual observations coincided with the middle of a wet and dry period respectively. The more lengthy series of data for stations in the northern plains area of the United States, studied by Mattice (12), also showed alternating periods of above- and below-average rainfall, but after each interval of deficiency there was a succeeding recovery, with, on the whole, no long-time trend in the direction of either dryness or wetness. Nevertheless, the presence of these fluctuations necessitates caution in dealing with supposedly "normal" or average values of either rainfall or crop yields calculated over a relatively short period of years; the possibilities of bias, through the unequal incidence of wet and dry periods, being obvious.

Successive dry and moist periods at both the American and Canadian stations were far from uniform either in duration or in amplitude of deviation from the average, and cannot therefore be regarded as truly periodic. It is, of course, possible that the observed secular variation is the resultant of several periodic components, but this could only be demonstrated by means of many additional annual observations. On the other hand, a study of random-difference series by Working (19) suggests that the temporal variation in question might have arisen from the cumulative effect of combinations of independent random fluctuations from year to year in the factors controlling precipitation. Certainly these results show nothing resembling the remarkable seven-years' periodicity of total rainfall in the Sudan Gezira, to which attention is directed by Crowther and Crowther (2). From the purely meteorological point of view, this aspect of the matter would seem to be worthy of further study.

Reference has already been made to a well known feature of the "plains" type of precipitation (10, 13), namely, the occurrence of the greater part of the annual total during the summer months. Secular variation in the amount falling was greater in the summer period, but the five-year moving average of the September 1–March 31 totals at the two stations in each district also showed secular movements, which were sometimes in the same direction but sometimes in opposition to those of the April 1–August 31 amounts (Fig. 3, broken lines). On the whole, these were probably of secondary importance, agriculturally, to the fluctuations in April 1–August 31 precipitation, since they include variations in winter snowfall, which are believed (1) to have little effect on soil moisture. Furthermore, as is pointed out by Koeppe (10), the moisture content of different falls of snow, as well as the extent of drifting, may vary considerably, thus adversely affecting the comparability of the observations. The amount of autumn and spring rainfall has, however, been shown to exert a significant influence upon the following season's wheat yield (6).

It should perhaps be emphasized again that the preceding discussion of the results shown in Fig. 3 refers to smoothed values representing the average trend of precipitation. As is apparent from Figs. 1 and 2, the individual amounts recorded at any station show pronounced irregular annual fluctuations. A dry season may sometimes occur in the midst of a period of above-average moisture, and *vice-versa*. For this reason, although the onset of periods, during which precipitation will be, in general, above- or below-average, may perhaps be inferred with a moderate degree of confidence, the conditions during any specified year must remain problematical.

Frequency Distribution of Seasonal and Monthly Totals

The frequency distribution, between two-inch class intervals, of the annual totals of precipitation during the periods April 1–August 31 and September 1–March 31, 1898–1934, at four individual stations, Edmonton, Calgary, Battleford and Swift Current, is illustrated in Figs. 4 and 5.

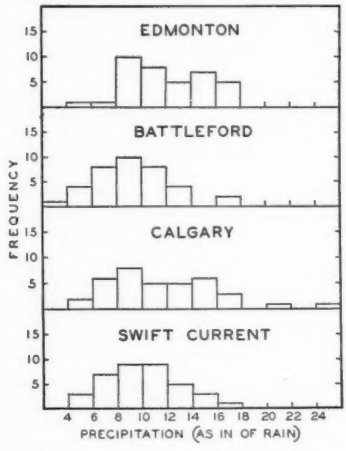

FIG. 4. *Frequency distribution of spring and summer (April 1 to Aug. 31) precipitation at meteorological stations in central and southern Saskatchewan and Alberta, 1898–1934.*

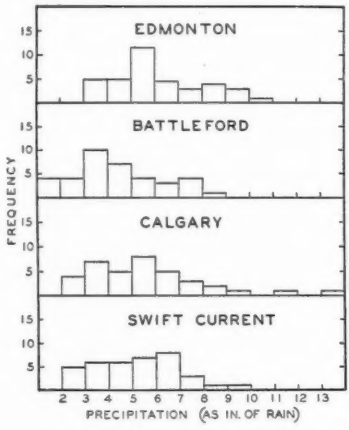

FIG. 5. *Frequency distribution of autumn and winter (Sept. 1 to March 31) precipitation at meteorological stations in central and southern Saskatchewan and Alberta, 1898–1934.*

During the period covered by these records, the general level of precipitation was clearly higher at Edmonton and Calgary than at either of the two Saskatchewan stations. The range of variation was greater at Calgary than at any of the other points, largely owing to the occurrence of a few exceptionally moist seasons. This enhanced variability is attributed to topographical effects, the proximity of Calgary to the Rocky mountain cordillera doubtless occasioning some special features in the local atmospheric circulation.

In spite of numerous irregularities, to be expected in view of the small sample of seasons available, the distributions in general incline towards symmetry, the seasonal totals for different years having tended to fluctuate around a central value. Those with precipitation in the vicinity of the average were, on the

whole, the more numerous, although in all four autumn and winter series the individual amounts were fairly evenly distributed over the range of variation.

Apart from the absence of gross asymmetry, however, little can be inferred from the available data, the number of years' observations at each station being too scanty to permit the statistical discrimination of any moderate degree of skewness. Lackey (11) has reported this to be a feature of the annual rainfall statistics for Nebraska; of the 56 years covered by observations at Lincoln, Neb., only 24 had an amount of precipitation above the average, whereas 32 were below-average. This situation seems not to prevail when the rainfall is of the monsoon type, Sankaranarayanan (17) concluding from a study of 60 or more years' records for a considerable number of stations, that there is very little justification for the assumption of non-normal annual deviations in monsoon rainfall over most of the plains of India.

Classification of the annual amounts of rain in the individual summer months April to August, inclusive, revealed interesting differences between months, not only in the average amount of precipitation received over the whole period of years, but also in its variation from year to year.

The frequency distributions for each month and station are shown in Fig. 6.

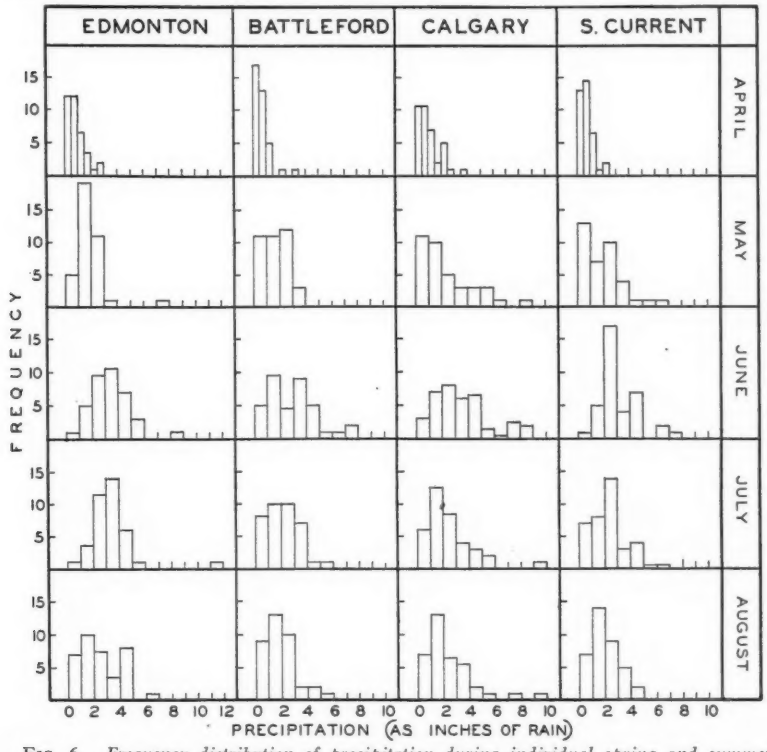

FIG. 6. *Frequency distribution of precipitation during individual spring and summer months at meteorological stations in central and southern Saskatchewan and Alberta, 1898-1934.*

At all four stations the annual distribution of April totals was markedly skew, years with the smaller amounts being the more numerous, and even moderate precipitation during this month being uncommon. In May and August there was a greater range of variation, and the skewness was less pronounced, particularly at Edmonton and Battleford, although in general below-average monthly totals were again more numerous than above-average ones. In June and July, on the average the wettest months, the total annual variation again increased, but there was a still further approach towards symmetry in the deviations, which, on the whole, tended to fluctuate about a central modal value, extreme wetness or dryness being relatively infrequent in these two months. As before, many chance discrepancies undoubtedly arose from the smallness of the number of observations available in each case.

Intra-seasonal Correlations

Association between the amount of precipitation in different periods of the same season, if present, is a climatic characteristic of obvious agricultural importance. In order to determine whether any such effects were distinguishable in the monthly and seasonal totals recorded at the preceding four representative stations, the analysis of these observations was continued by the calculation of the various correlation coefficients shown in Table I.

TABLE I

COEFFICIENTS OF CORRELATION (*r*) BETWEEN PRECIPITATION IN DIFFERENT PERIODS OF THE SAME SEASON

(37 years' data)

Periods	Edmonton	Calgary	Battleford	Swift Current
Sept.–Mar. × April–Aug.	0.14	0.23	0.13	−0.02
April × May	.01	−.21	.13	−.23
× June	−.29	−.06	−.13	−.29
× July	.04	−.11	.10	−.15
× August	.23	−.32	−.08	.17
May × June	−.10	.33	.03	.04
× July	.06	.25	.08	.27
× August	.03	.20	.36	.14
June × July	.02	.25	.12	.16
× August	.15	−.15	−.11	−.30
July × August	−.10	−.08	.11	.16

5% point = 0.33

These coefficients are all small, and only two of the 44 values exceed the 5% point (4, Sec. 34), *i.e.*, just the proportion to be expected as a result of chance combinations, in the number of seasons examined. Although at all four stations there occurred some years in which periods of above- or below-average rainfall extended into two successive summer months, it must be

concluded that these were not sufficiently frequent to be regarded as a general feature of the climate. In the long run the amounts of precipitation in the five months considered seem to have fluctuated independently from year to year. This is the more noteworthy in view of the secular variations in the five-monthly totals, discussed above. An explanation may perhaps be found in the fact that the weather of this region is predominantly influenced by cyclones (10), the behavior of each of which will be governed by a number of independently varying factors.

There was likewise no consistent relation between the total precipitation from September 1 to March 31 and that during the succeeding April 1 to August 31, from season to season.

Characteristics of Daily Precipitation

Further details of agricultural interest emerged from an examination of the records of daily precipitation during the summer months at Edmonton, Calgary, Saskatoon and Swift Current, now published by the Meteorological Service of Canada for the years 1916–1932, inclusive (15).

The pronounced seasonal march in the average amounts of rain received at these and neighbouring stations during the spring and summer months was commented upon in a previous paper (5). The 31-year average was found progressively to increase from the low value of one inch or less in April to a maximum of three inches or more in June, after which there was again a diminution in July and August, such a progression being typical of the "northern plains" type of precipitation (13). Turning now to the statistics of the number of days on which a measurable amount of rain (0.01 in. or more) fell, these also were found to exhibit a somewhat similar trend, as indicated in Table II. This variation in the number of rainy days per month was not, however, in direct proportion to that of the total rainfall, with the result that the average amount of rain per day on which rain fell also changed from month to month, attaining its maximum in June and July. The values of this average, for the four stations, are given in Table III.

TABLE II

PERCENTAGE OF DAYS ON WHICH A MEASURABLE AMOUNT OF RAIN FELL, 1916–1932

Station	April	May	June	July	August
Edmonton	26.7	31.3	43.3	42.1	42.7
Calgary	27.8	29.8	40.0	29.2	29.0
Saskatoon	21.2	27.1	38.8	31.9	29.2
Swift Current	27.8	28.5	38.4	30.0	27.5

TABLE III

AVERAGE AMOUNT OF RAIN (INCHES) PER DAY ON WHICH RAIN FELL, 1916–1932

Station	April	May	June	July	August
Edmonton	0.12	0.18	0.25	0.23	0.18
Calgary	0.15	0.17	0.26	0.26	0.21
Saskatoon	0.13	0.17	0.22	0.26	0.19
Swift Current	0.11	0.19	0.25	0.25	0.23

The moderate skewness noted above in the frequency distribution of the monthly totals becomes much more pronounced when the frequency of occurrence of different daily amounts in each month is considered. This is exemplified in Fig. 7, showing the partition of the individual daily totals, exclusive of zero, between successive class intervals of 0.10 in. In all five months at each station, the most numerous class was that comprising the smallest daily amounts, 0.10 in. and less; and the frequency of occurrence diminished progressively in the higher classes.

It was noted in a preceding paragraph that June and July, the months in which total precipitation was on the average highest, had not only the greatest number of rainy days, but also the largest average amount of precipitation per rainy day. This qualitative differentiation is further illustrated in Fig. 7, where it may be observed that these months were characterized by the occurrence of a few outstandingly large daily amounts, which materially extend the range of the frequency distribution and contribute appreciably to the increase in the average.

Supplementing this information respecting the frequency of precipitation of specified daily amounts, Fig. 8 shows the actual amount of rain contributed during the 17-year period by the daily falls of each class. Here a further sub-classification was introduced. The 17 annual totals for each month at each station were arranged in order of magnitude, and the eight driest Aprils, Mays, etc., identified. The total height of each column in Fig. 8 was then made representative of the aggregate rain received in daily amounts of the specified size during the entire 17 years, and the lower blackened part indicative of the proportion of this aggregate received during the eight driest months.

Considering first the totals for the entire 17-year period, a considerable fraction of all the rain received in April, May and August occurred in the form of daily amounts of 0.30 in. or less. In June and July such small daily amounts were offset to some extent by large rainfalls which, although occurring relatively infrequently, nevertheless accounted for an appreciable proportion of the total, particularly at the two Alberta stations, where the general level of precipitation was higher.

It may also be observed from Fig. 8 that all the months and stations included showed a qualitative differentiation between the precipitation of the whole 17 years and that during the eight driest periods, such that the latter were characterised not only by a smaller total precipitation, but also by an almost complete absence of daily amounts in excess of one inch. Consequently in such dry periods the fraction of the total precipitation accruing from small falls was correspondingly increased.

Obviously, the manner of occurrence of precipitation may be of great agricultural importance in determining the effectiveness of the total amount received. Much of the moisture falling in the form of light showers must be rapidly lost by evaporation from the surface layer of soil, never becoming available for absorption by plants. Thus in the opinion of Barnes and Hopkins (1), under western Canadian conditions rainfalls of less than 0.25 in.

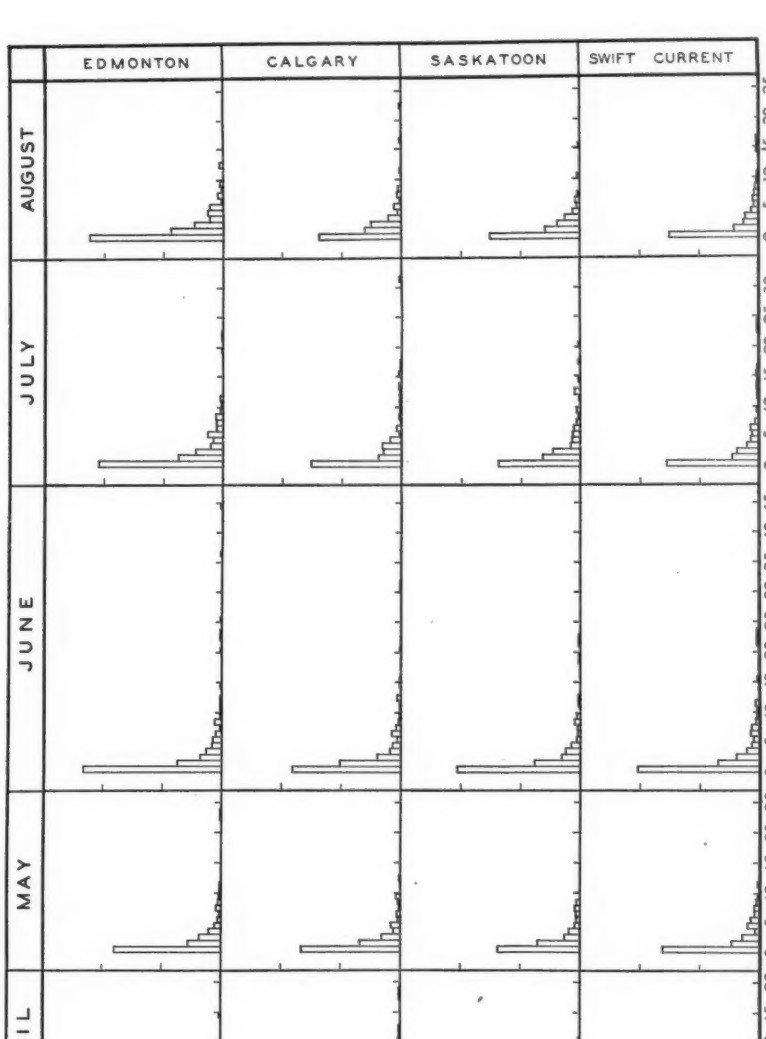

FIG. 7. *Frequency distribution of daily totals of precipitation (excluding zero) at meteorological stations in central and southern Saskatchewan and Alberta during individual spring and summer months, 1916–1932.*

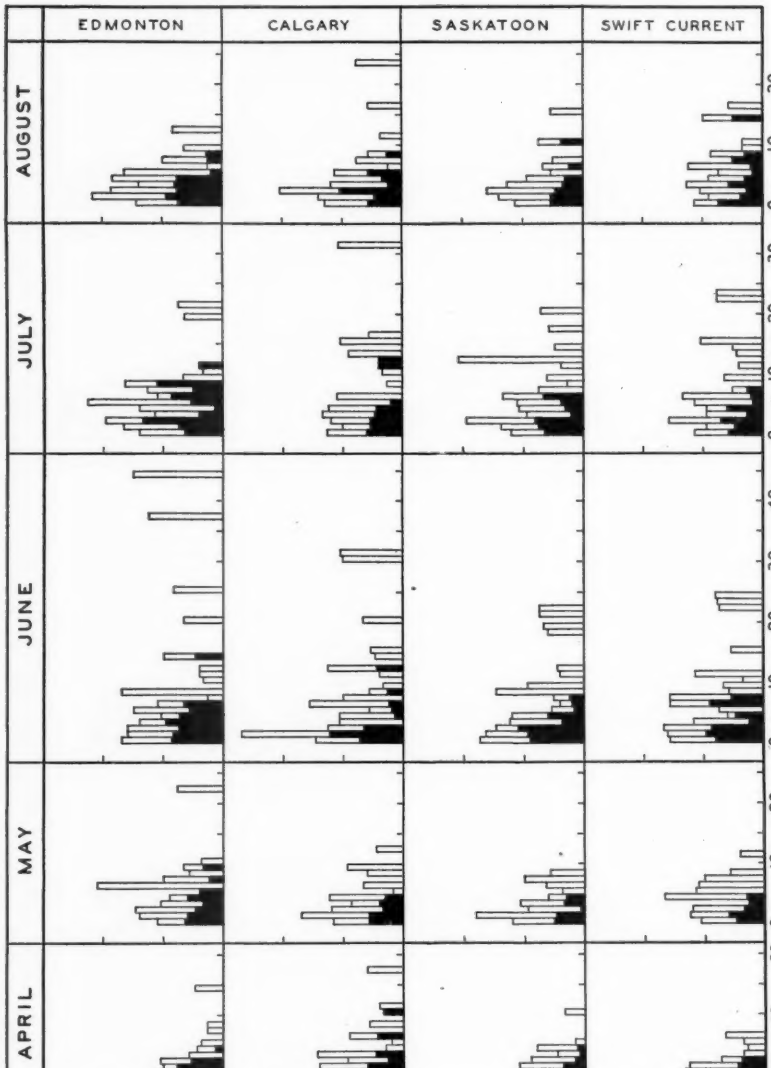

FIG. 8. *Proportion of total precipitation at meteorological stations in central and southern Saskatchewan and Alberta during individual spring and summer months, 1916–1932, received in daily amounts of specified sizes: (A) During entire period (total height of column); (B) During the eight driest Aprils, Mays, etc., at each station (lower blackened portion).*

may be of little benefit in increasing soil moisture; similarly, Daniel and Harper (3) adopted 0.50 in. per day as the lower limit of effective rainfall in Oklahoma; and McLaughlin, Blaney and Taylor (14), considering the disposition of rainfall in the Santa Ana river area of California, state that during the wet winter months "the best data available indicate that the average direct evaporation loss from the soil is about one-half acre inch per acre after each fall of rain equalling or exceeding that amount. For smaller rainfalls the entire amounts are evaporated." On the other hand, very heavy downpours lead to some loss of moisture through surface run-off, the optimum amount of unit rain consequently having an upper as well as a lower limit. In these circumstances the force of McLaughlin, Blaney and Taylor's contention (14) that "every rainfall period must be studied separately in order to arrive at the penetration for the season, since the same seasonal precipitation gives entirely different amounts of penetration under different conditions of intensity and distribution," can hardly be denied.

Table IV, obtained by summing the individual class totals represented in Fig. 8, shows the actual proportion of the total precipitation of each month at each station received in daily amounts of 0.30 in. or less, 0.31–1.50 in. and over 1.50 in., during the entire 17 years. Table V provides the corresponding figures for the eight driest Aprils, Mays, etc.

From 42 to 66% of the total April precipitation at the individual stations during the 17 years (Table IV) occurred in amounts of 0.30 in. or less per

TABLE IV

PROPORTION OF TOTAL MONTHLY PRECIPITATION OCCURRING IN VARIOUS DAILY AMOUNTS, 1916–1932

Month	Station	Statistic	Precipitation in daily amounts of		
			0.01–0.30 in.	0.31–1.50 in.	Over 1.50 in.
April	Edmonton	17-yr. av., in.	0.56	0.42	0.00
		Per cent. of total	57	43	0
	Calgary	17-yr. av., in.	0.60	0.73	0.11
		Per cent. of total	42	51	7
	Saskatoon	17-yr. av., in.	0.51	0.32	0.00
		Per cent. of total	62	38	0
	Swift Current	17-yr. av., in.	0.58	0.30	0.00
		Per cent. of total	66	34	0
May	Edmonton	17-yr. av., in.	0.70	0.91	0.14
		Per cent. of total	40	52	8
	Calgary	17-yr. av., in.	0.72	0.86	0.00
		Per cent. of total	45	55	0
	Saskatoon	17-yr. av., in.	0.69	0.74	0.00
		Per cent. of total	48	52	0
	Swift Current	17-yr. av., in.	0.62	1.08	0.00
		Per cent. of total	36	64	0

TABLE IV—*Concluded*

PROPORTION OF TOTAL MONTHLY PRECIPITATION OCCURRING IN VARIOUS DAILY AMOUNTS, 1916–1932—*Concluded*

Month	Station	Statistic	Precipitation in daily amounts of		
			0.01–0.30 in.	0.31–1.50 in.	Over 1.50 in.
June	Edmonton	17-yr. av., in.	0.87	1.61	0.75
		Per cent. of total	27	50	23
	Calgary	17-yr. av., in.	0.96	1.47	0.57
		Per cent. of total	32	49	19
	Saskatoon	17-yr. av., in.	0.85	1.25	0.48
		Per cent. of total	33	48	19
	Swift Current	17-yr. av., in.	0.85	1.47	0.51
		Per cent. of total	30	52	18
July	Edmonton	17-yr. av., in.	0.89	1.79	0.24
		Per cent. of total	31	61	8
	Calgary	17-yr. av., in.	0.61	1.08	0.47
		Per cent. of total	28	50	22
	Saskatoon	17-yr. av., in.	0.80	1.58	0.22
		Per cent. of total	31	61	8
	Swift Current	17-yr. av., in.	0.64	1.20	0.45
		Per cent. of total	28	52	20
August	Edmonton	17-yr. av., in.	0.96	1.39	0.00
		Per cent. of total	41	59	0
	Calgary	17-yr. av., in.	0.83	0.81	0.24
		Per cent. of total	44	43	13
	Saskatoon	17-yr. av., in.	0.73	0.81	0.09
		Per cent. of total	45	50	5
	Swift Current	17-yr. av., in.	0.54	1.28	0.10
		Per cent. of total	28	67	5

day, and hence may have been to a considerable extent ineffective in increasing soil moisture. (It should, however, be noted that since the rate of evaporation and transpiration from the soil depends on the evaporating power of the air, which itself changes progressively from month to month (9), the minimum effective rainfall probably also shows some seasonal trend.) In subsequent months, the average amount of rain falling on each rainy day was greater, resulting in a reduction of the average fraction of the total accounted for by daily quantities of 0.30 in. or less to 27–33% in June and 28–31% in July. At the same time, however, up to 23% of the total now fell in large amounts of over 1.50 in. per day, so that the amount received in the central and perhaps most efficient daily range rose only from 34–51% in April to 48–52% in June and 50–61% in July, although in the latter months, of course, this percentage represented a considerably greater absolute quantity of moisture.

Not all the moisture precipitated in even the largest daily falls is, of course, lost by surface run-off; indeed it seems likely that in western Canada the major part is conserved. The actual amounts thus lost will depend on the intensity of precipitation, on local topography, and on the texture and moisture-deficiency of the soil (16). According to Taggart (18), the run-off from southern Saskatchewan has been estimated to be less than 2% of the total (presumably annual) precipitation. This figure is, however, probably exceeded in districts where greater amounts and intensities of rain are experienced.

The diminution in average unit rainfall, as well as in total amount, in the eight driest instances of each month, is shown numerically in Table V. In April, from 54 to 100% of the total rain at the four stations was in daily amounts of 0.30 in. or less, and even in June small falls of this nature constituted on the 8-year average from 45 to 68% of the total. The sparse

TABLE V

PROPORTION OF TOTAL MONTHLY PRECIPITATION OCCURRING IN VARIOUS DAILY AMOUNTS DURING THE EIGHT DRIEST MONTHS, 1916–1932

Month	Station	Statistic	Precipitation in daily amounts of		
			0.01–0.30 in.	0.31–1.50 in.	Over 1.50 in.
April	Edmonton	8-yr. av., inches	0.66	0.05	0.00
		Per cent. of total	93	7	0
	Calgary	8-yr. av., inches	0.54	0.47	0.00
		Per cent. of total	54	46	0
	Saskatoon	8-yr. av., inches	0.38	0.10	0.00
		Per cent. of total	79	21	0
	Swift Current	8-yr. av., inches	0.53	0	0.00
		Per cent. of total	100	0	0
May	Edmonton	8-yr. av., inches	0.64	0.57	0.00
		Per cent. of total	53	47	0
	Calgary	8-yr. av., inches	0.54	0.26	0.00
		Per cent. of total	67	33	0
	Saskatoon	8-yr. av., inches	0.40	0.24	0.00
		Per cent. of total	62	38	0
	Swift Current	8-yr. av., inches	0.52	0.11	0.00
		Per cent. of total	82	18	0
June	Edmonton	8-yr. av., inches	0.90	1.10	0.00
		Per cent. of total	45	55	0
	Calgary	8-yr. av., inches	0.98	0.47	0.00
		Per cent. of total	68	32	0
	Saskatoon	8-yr. av., inches	1.10	0.60	0.00
		Per cent. of total	65	35	0
	Swift Current	8-yr. av., inches	1.00	0.79	0.00
		Per cent. of total	56	44	0

TABLE V—*Concluded*

PROPORTION OF TOTAL MONTHLY PRECIPITATION OCCURRING IN VARIOUS DAILY AMOUNTS DURING THE EIGHT DRIEST MONTHS, 1916–1932—*Concluded*

Month	Station	Statistic	Precipitation in daily amounts of		
			0.01–0.30 in.	0.31–1.50 in.	Over 1.50 in.
July	Edmonton	8-yr. av., inches	1.01	1.48	0.00
		Per cent. of total	41	59	0
	Calgary	8-yr. av., inches	0.63	0.64	0.00
		Per cent. of total	50	50	0
	Saskatoon	8-yr. av., inches	0.81	0.58	0.00
		Per cent. of total	58	42	0
	Swift Current	8-yr. av., inches	0.65	0.56	0.00
		Per cent. of total	54	46	0
August	Edmonton	8-yr. av., inches	0.90	0.86	0.00
		Per cent. of total	51	49	0
	Calgary	8-yr. av., inches	0.78	0.40	0.00
		Per cent. of total	66	34	0
	Saskatoon	8-yr. av., inches	0.70	0.46	0.00
		Per cent. of total	60	40	0
	Swift Current	8-yr. av., inches	0.52	0.77	0.00
		Per cent. of total	40	60	0

amount of moisture which was actually received in the dry periods was thus further reduced in average effectiveness by its disadvantageous distribution. In some instances, moreover, this situation prevailed to an extent not brought out by the average values listed in Table V, but illustrated in Fig. 9. Here, the rainfall at Calgary and Saskatoon in June of each of the 17 years, 1916–1932, is represented by a point, of which the horizontal co-ordinate specifies the monthly total and the vertical co-ordinate the proportion of this total occurring in daily quantities of 0.30 in. or less. In the moister months, this proportion was in the neighbourhood of 20%; in those of smaller total precipitation it was on the average higher, as indicated in Table V, but fluctuated considerably in different years. In several instances it attained 100%, but in others was only of the order of 40%; and in one year at Saskatoon only 10% of a June rainfall totalling but 2.04 in. occurred in amounts of 0.30 in. per day or less.

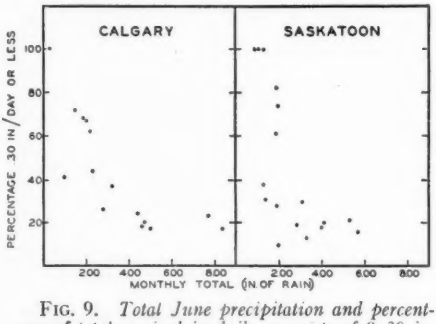

FIG. 9. *Total June precipitation and percentage of total received in daily amounts of 0.30 in. or less, at Calgary, Alberta, and Saskatoon, Saskatchewan, 1916–1932.*

This provides a further illustration of the fact that similar amounts of total precipitation may be very differently distributed in different seasons, which is of interest since it applies to periods of below-average moisture, when the penetration into the soil of the limited amounts of rain that do fall is particularly important.

Although many of the smaller daily rainfalls probably did not result in any significant increase in soil moisture, it may be presumed that the lower temperatures and increased atmospheric humidity associated with them had some effect in temporarily reducing the rate of removal of water from the soil by evaporation and transpiration. It is, therefore, desirable to know whether there was a close correlation between the total amount of rain falling in a specified month and the number of rainy days, or whether the effects of drought may be mitigated in some cases in the manner just mentioned. Fig. 10 shows the relation between total precipitation and number of rainy

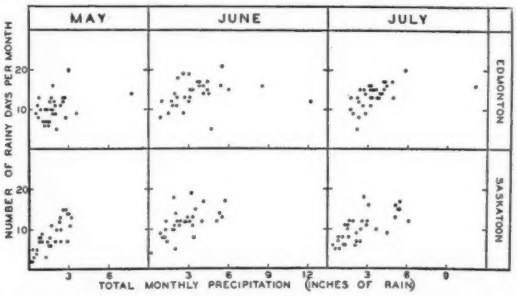

FIG. 10. *Total precipitation and number of rainy days (0.01 in. or more) per month at Edmonton, Alberta, and Saskatoon, Saskatchewan, 1900–1932.*

days per month for May, June and July, 1900–1932, at Edmonton and Saskatoon. It will be seen that in general the number of rainy days was definitely lower during the drier months, particularly in the more arid periods experienced at Saskatoon.

Local Variation in Precipitation

As is well known, the amount of precipitation during an individual rainstorm is subject to considerable local variation. In connection with the forecasting of agricultural production from weather data, the question therefore arises as to the accuracy with which observations at a limited number of meteorological stations are capable of portraying annual differences in the averages of precipitation, temperature and other components of the weather, over the considerable area (of the order of thousands of square miles) comprised by any of the Alberta and Saskatchewan crop districts.

This will, of course, depend in each case on the degree of correlation between the annual differences in the weather factor in question in individual sectors of the district. If the correlation is high, relatively few stations, situated at some distance apart, will suffice to provide a reliable indication of the

situation prevailing. Conversely, irregular or largely independent variation from year to year, for example such that some localities within the district suffered drought whilst others received at the same time an above-average amount of rain, would necessitate a larger number of stations more closely spaced.

Local Variation in Monthly Totals of Precipitation

To provide some quantitative information on this subject, the precipitation during the months of April, May, June, July and August of 10 or more separate years at a number of stations (8 to 10) in each of the four areas, central and southern Saskatchewan and Alberta, was examined in some detail. Fig. 11 shows the location of the four series of stations used

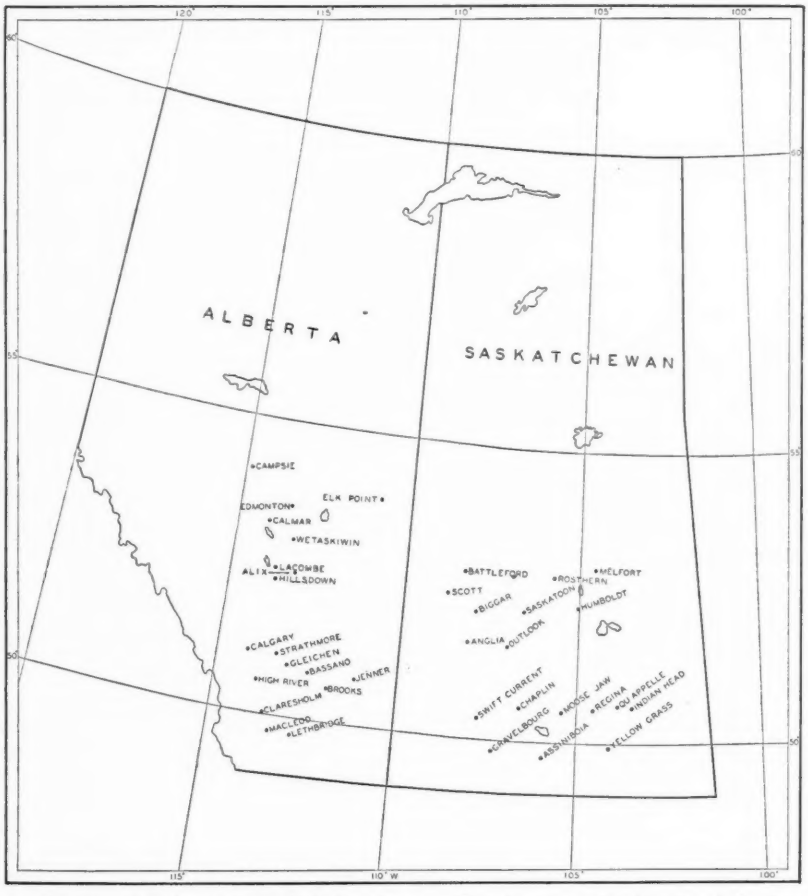

FIG. 11. *Location of meteorological stations providing data for study of local variation in precipitation.*

for this purpose; in each case a more compact grouping would have been preferable, but this could not be achieved owing to the lack of intervening stations with the required continuity of observations.

A typical example of the data thus assembled is given in Table VI, namely, total precipitation during the month of June in different years at 10 stations in southern Saskatchewan. Each row of figures in this table provides nine

TABLE VI

JUNE PRECIPITATION (INCHES OF RAIN) AT STATIONS IN SOUTHERN SASKATCHEWAN

Year	Indian Head	Moose Jaw	Qu'Appelle	Regina	Yellowgrass	Yorkton	Aneroid	Assiniboia	Chaplin	Swift Current	Mean
1923	6.99	5.03	8.22	6.09	4.83	4.90	9.33	4.18	3.93	6.82	6.03
24	2.22	1.35	2.18	1.52	2.54	1.29	4.31	2.83	4.38	2.50	2.51
25	3.47	7.11	5.30	6.29	5.88	3.59	2.24	4.15	2.93	1.56	4.25
26	1.99	2.00	2.10	1.78	4.43	1.08	4.34	5.30	.91	2.33	2.63
27	1.96	.88	1.16	2.56	1.36	3.49	2.80	1.71	1.09	1.11	1.81
28	6.05	6.07	4.68	5.56	5.18	3.37	4.63	5.53	6.11	4.80	5.20
29	1.12	1.31	1.16	1.93	1.06	.83	1.48	.67	.78	3.07	1.34
1930	2.35	2.31	4.55	2.91	3.32	3.10	1.67	2.51	2.68	4.05	2.94
31	1.18	3.95	1.54	2.48	2.00	2.35	1.65	3.23	2.15	2.45	2.30
32	3.44	5.73	4.18	3.15	4.41	3.35	2.05	4.98	4.35	2.62	3.83
Mean	3.08	3.57	3.51	3.43	3.50	2.74	3.45	3.51	2.93	3.13	3.28

degrees of freedom (4) for the estimation of the average magnitude of local fluctuations in the amount of June rain. However, the observed differences between stations may have been occasioned in part by the fact that some localities had a consistently higher or lower rainfall than others. This portion of the variance, being a factor common to all years, will not affect the accuracy with which the yearly averages indicate differences between years in the area as a whole (provided, of course, that the same series of stations is maintained throughout), and hence should be excluded from an estimate of the uncertainty attached to these averages. Following the procedure of Fisher (4, Chap. 7), the sum of the squares of the deviations of the 100 individual observations in Table VI from their general mean of 3.28 in. may in fact be divided into three additive portions, one due to annual differences in the average rainfall at all 10 stations (means of rows in Table VI), another due to differences in the average rainfall over the 10-year period at individual stations (means of columns) and a third arising from irregular variations in the individual monthly amounts after allowing for average differences between years and stations.

Such an analysis was made of each of the 20 series of observations provided by the precipitation in different years, during the five months referred to, at the specified stations in each of the four districts (2,052 individual monthly totals in all). The numerical results obtained are shown in Table VII.

The most pronounced characteristic of these is the fact that for each of the five months, in all four areas, the mean square due to variations in the

TABLE VII

ANALYSIS OF VARIANCE OF TOTAL MONTHLY RAINFALL

District	Variance due to	April		May		June		July		August	
		Deg. of freedom	Mean square	Deg. of freedom	Mean square	Deg. of freedom	Mean square	Deg. of freedom	Mean square	Deg. of freedom	Mean square
Central Alberta	Years	10	5.4827**	9	4.0725**	9	16.1850**	9	3.8883**	10	7.5863**
	Stations	7	.4158	7	1.4538**	7	1.1028	7	2.3161*	7	2.9821**
	Remainder	70	.3467	63	.4396	63	1.4975	63	1.0116	70	.7621
Southern Alberta	Years	11	6.6030**	10	23.3221**	11	22.6095**	11	6.6254**	11	8.1307**
	Stations	9	1.4231**	9	.5709	9	7.7087**	9	.8866	9	2.1091*
	Remainder	99	.5838	90	1.0130	99	1.4987	99	.7119	99	.7988
Central Saskatchewan	Years	11	1.4471**	11	8.8431**	11	16.9358**	10	16.5129**	11	6.9340**
	Stations	8	.3279	9	.0774	9	.6102	9	1.2383	8	1.4659*
	Remainder	88	.2263	99	.3973	99	1.0223	90	.9149	88	.3614
Southern Saskatchewan	Years	9	1.2178	9	13.0106	9	22.4273**	9	13.3582**	9	8.4212**
	Stations	8	.2100	8	.5862	9	.8033	9	1.7563*	9	.4500
	Remainder	72	.2053	72	.5365	81	1.5065	81	.9378	81	.3362

Mean squares due to Years and Stations which are significantly greater than the corresponding Remainder are indicated by asterisks.

**Exceeds 5% point.*

***Exceeds 1% point.*

yearly averages was very significantly greater than the mean square remainder. This indicates that there was, as might be expected, a definite correlation between the amounts of rain recorded at different stations in the same area during the same month. Some very clear examples of this may be observed in Table VI. In June, 1928, the mean precipitation at the various stations in southern Saskatchewan was decidedly above-average; and it will be seen that all 10 stations listed registered an amount considerably in excess of their respective 10-year averages. Similarly in 1929 the same stations all received below-average precipitation. These are, of course, extreme cases, but there is no doubt about the general presence of intra-monthly correlation in the precipitation at stations in the same region. It may be recollected, however, that this correlation did not extend to the amounts recorded in successive months at the same station (Table I).

Differences between stations over the 10-year period, measured by the mean squares "between stations" of Table VII, were not nearly so marked; this also might have been anticipated, in view of the absence of important topographical barriers within the districts. There were isolated instances in which some stations received significantly higher or lower average amounts of rain during certain of the five months considered than did other stations in the same district. As a rule, however, such effects, if indeed present, were not sufficiently pronounced to stand out from the remaining irregular variation.

This last, which gave rise to the mean squares or variances shown in the third, sixth, ninth and twelfth rows of Table VII, is treated in more detail in Table VIII. The first row of figures relating to each district gives the standard deviations, in inches of rain, obtained by taking the square root of the mean square remainders in Table VII, and indicates directly the uncertainty with which observations at individual stations represented variations in the amount of precipitation over the area as a whole from year to year during the months specified. The second line shows in each case this standard deviation expressed as a percentage of the corresponding mean monthly rainfall of the district, *i.e.*, the general mean of all stations over the entire period of years.

It will be seen that in addition to the intra-monthly covariation already discussed, there was an appreciable amount of irregular fluctuation in the amount of rain falling at different stations in the same district during the same month. June was the most variable month in respect of actual amount of rain, the intra-monthly, inter-station standard deviations shown in Table VIII ranging from 0.96 in. for the central Alberta stations to 1.24 in. for those in southern Saskatchewan. Assuming that the fluctuations occur with relative frequencies approximating those of a "normal" or gaussian distribution, then if observations in southern Saskatchewan were confined to a single station, the amount of June rain recorded at that station would be expected to deviate from the mean for the district as a whole by 2.03 in. or more once in 10 years on the average, and by 2.43 in. or more once in each 20 years in the long run.

TABLE VIII

STATISTICS OF LOCAL VARIATION IN TOTAL MONTHLY RAINFALL

District	Statistic	April	May	June	July	August
Central Alberta	Standard deviation (inches)	0.59	0.66	1.22	1.01	0.87
	S.D. as per cent. of district mean	50	41	42	41	35
	No. of stations required to reduce S.D. to 10%	25	16	18	16	12
	No. of stations required to reduce S.D. to 0.20 in.	9	11	37	26	19
Southern Alberta	Standard deviation (inches)	0.73	0.99	1.23	0.84	0.89
	S.D. as per cent of district mean	49	53	39	44	56
	No. of stations required to reduce S.D. to 10%	24	28	15	19	32
	No. of stations required to reduce S.D. to 0.20 in.	13	25	38	18	20
Central Saskatchewan	Standard deviation (inches)	0.48	0.63	1.01	0.94	0.60
	S.D. as per cent. of district mean	54	43	37	43	37
	No. of stations required to reduce S.D. to 10%	30	18	14	19	13
	No. of stations required to reduce S.D. to 0.20 in.	6	10	26	22	9
Southern Saskatchewan	Standard deviation (inches)	0.45	0.73	1.24	0.97	0.58
	S.D. as per cent. of district mean	56	49	38	48	36
	No. of stations required to reduce S.D. to 10%	31	24	14	23	13
	No. of stations required to reduce S.D. to 0.20 in.	5	13	38	24	8

The records for the other four months show less variation in the absolute amount of rain, but in proportion to the average monthly total, April was in fact the most variable, the intra-monthly standard deviation of the observations at individual stations in the various districts being from 49 to 56% of the mean.

Clearly, as previously suggested (6), observations at one station only in each district would be quite inadequate as an index of precipitation for crop estimating. As a matter of interest, the theoretical number of stations required to reduce the standard deviation of their mean to 10% in each case, or alternatively to a uniform level of 0.20 in. per month, was calculated and is given in the last two lines of each section of Table VIII.

Considered from the point of view of determining accurately the amount of rainfall in an agricultural district, such local variability is, of course, an unwelcome source of error. On the other hand, it may prove to be of direct advantage to the agricultural meteorologist, who seeks to ascertain by statistical methods the correlation between weather conditions and crop growth

and yield. In recently settled provinces such as Alberta and Saskatchewan, the available series of crop and weather data for periods of years at the same place are not lengthy enough to permit the study of weather effects in any detail. If, however, the weather during the same season varies appreciably from place to place within a homogeneous soil zone, and crop yields at these places are determined to a fair degree of accuracy, this intra-annual, spatial variation and co-variation, accumulated over a relatively small number of years, may make possible much more extensive correlation studies.

The individual monthly totals were also used as described below to provide some information respecting local variation in precipitation during wet and dry periods. Obviously, during a widespread drought, large differences in rainfall from point to point in the area affected are impossible. When moisture is more abundant, however, the trend of local fluctuations is less readily predictable *a priori*. It was suggested to the writer that a high average of precipitation throughout a district is most likely to result from the occurrence of several general rains, whereas, in a period of intermediate precipitation, local showers may account for a greater proportion of the total. Should this be so, local variation might in fact be greatest during such intermediate periods.

To test this point the mean square deviation between stations in each district was computed for the months of May and June of each year, and is shown plotted against the corresponding average precipitation in Figs. 12 and 13. The May results indicate definitely that the months of maximum precipitation were also those of maximum local variability. In June the situation was not so clear-cut. Some of the periods of intermediate moisture,

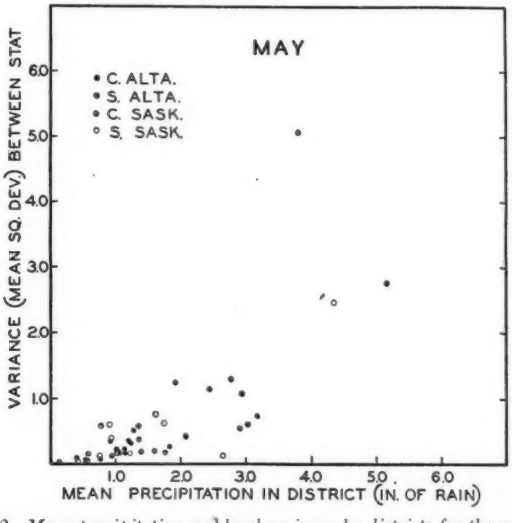

FIG. 12. *Mean precipitation and local variance by districts for the month of May, 1922–1932.*

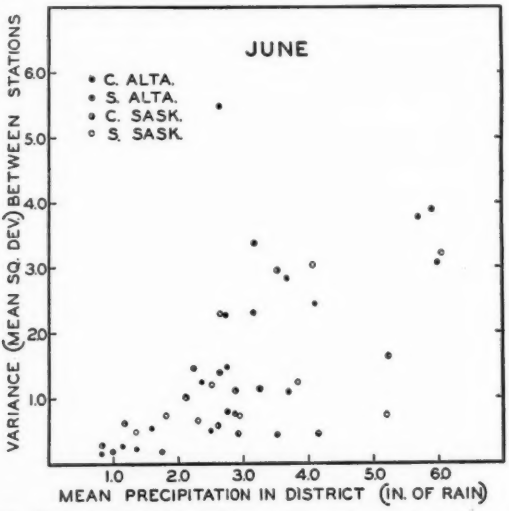

FIG. 13. *Mean precipitation and local variance by districts for the month of June, 1922–1932.*

particularly in southern Alberta, were characterized by large local variation; others, however, were below-average in this respect, and on the whole the tendency in this month also was for the amount of local variation to increase with increasing average precipitation.

Local Variation in Intensity of Precipitation

In order to ascertain whether the monthly quantities of rain received in daily amounts exceeding 0.30 in. displayed local fluctuations differing in any way from those of the total rainfall, the variance of the former quantity in each district was also examined. Owing to the labor involved in classifying the daily amounts recorded during each of the hundreds of station-months concerned, this operation was confined to the observations for May, June and July. The final results of the analysis of variance are shown in Table IX.

Generally speaking, the qualitative features of the variation are similar to those noted in the preceding discussion of total rainfall. There are still pronounced intra-monthly correlations between the amounts registered at stations in the same district, and infrequent significant differences in the 9- or 10-year average between stations. As before a considerable proportion of the total variance is attributable to irregular local differences. These were, in fact, relatively more pronounced than were the local variations in total precipitation, dealt with in Tables VII and VIII; for although rains of more than 0.30 in. per day at representative stations in each district constituted on the average only 55-70% of the total monthly precipitation (Table IV), the mean square remainders listed in Table IX are of the same order as those in Table VII. This greater relative variability of the heavier falls is shown more clearly by a comparison of the corresponding entries in Table VIII and Table X.

TABLE IX

ANALYSIS OF VARIANCE OF TOTAL MONTHLY RAIN RECEIVED IN AMOUNTS EXCEEDING 0.30 IN. PER DAY

District	Variance due to	May		June		July	
		Deg. of freedom	Mean square	Deg. of freedom	Mean square	Deg. of freedom	Mean square
Central Alberta	Years	9	1.9916**	8	14.7778**	7	5.7772**
	Stations	7	1.2344**	7	1.1057	7	1.7642
	Remainder	63	.4023	56	1.4480	49	1.0460
Southern Alberta	Years	9	17.4276**	10	12.8697**	9	2.5996**
	Stations	9	.8753	9	9.3074**	9	.6669
	Remainder	81	1.1711	90	1.7481	81	.6558
Central Saskatchewan	Years	10	5.4162**	9	8.6369**	10	10.1631**
	Stations	8	.2202	8	.5628	8	.8710
	Remainder	80	.4543	72	1.1967	80	.8160
Southern Saskatchewan	Years	9	7.5061**	9	19.6294**	9	10.3919**
	Stations	7	.8706	8	1.2604	9	1.2716
	Remainder	63	.6052	72	1.7615	81	.9924

Mean squares due to Years and Stations which are significantly greater than the corresponding Remainder are indicated by asterisks.

**Exceeds 5% point.*

***Exceeds 1% point.*

TABLE X

STATISTICS OF LOCAL VARIATION IN TOTAL MONTHLY RAIN RECEIVED IN AMOUNTS EXCEEDING 0.30 IN. PER DAY

District	Statistic	May	June	July
Central Alberta	Standard deviation (inches)	0.63	1.20	1.02
	S.D. as per cent. of district mean	66	58	61
	No. of stations required to reduce S.D. to 10%.	44	34	37
	No. of stations required to reduce S.D. to 0.20 in.	10	36	26
Southern Alberta	Standard deviation (inches)	1.08	1.32	0.81
	S.D. as per cent. of district mean	78	52	70
	No. of stations required to reduce S.D. to 10%	61	27	49
	No. of stations required to reduce S.D. to 0.20 in.	29	44	16
Central Saskatchewan	Standard deviation (inches)	0.67	1.10	0.90
	S.D. as per cent. of district mean	72	66	61
	No. of stations required to reduce S.D. to 10%	52	44	37
	No. of stations required to reduce S.D to 0.20 in.	11	30	20
Southern Saskatchewan	Standard deviation (inches)	0.77	1.33	1.00
	S.D. as per cent. of district mean	77	54	73
	No. of stations required to reduce S.D. to 10%	59	29	53
	No. of stations required to reduce S.D. to 0.20 in.	15	44	25

In view of the variation from year to year at the same station in the percentage of the total precipitation of a specified month received in daily amounts exceeding 0.30 in. illustrated in Fig. 9, it seemed desirable to examine the local fluctuations in this quantity also, thus supplementing the analysis shown in Table IX. Accordingly, the individual monthly percentages were determined and the variance of these partitioned as before into portions due to differences between years, to differences between station averages, and to the remaining irregular local fluctuations. The resulting mean squares are shown in Table XI.

TABLE XI

ANALYSIS OF VARIANCE OF PERCENTAGE OF TOTAL MONTHLY RAIN RECEIVED IN AMOUNTS EXCEEDING 0.30 IN. PER DAY

District	Variance due to	May		June		July	
		Deg. of freedom	Mean square	Deg. of freedom	Mean square	Deg. of freedom	Mean square
Central Alberta	Years	9	787.33	8	1086.23**	7	2012.94*
	Stations	7	2055.87**	7	669.80	7	940.21
	Remainder	63	529.07	56	342.70	49	671.64
Southern Alberta	Years	9	5429.18**	10	907.86*	9	1481.71
	Stations	9	789.22	9	1036.09**	9	1122.47
	Remainder	81	730.71	90	404.41	81	861.80
Central Saskatchewan	Years	10	4089.98**	9	3847.52**	10	4546.62**
	Stations	8	342.38	8	590.47	8	959.50
	Remainder	80	854.07	72	646.59	80	696.36
Southern Saskatchewan	Years	9	3636.55**	9	1662.41**	9	4243.29**
	Stations	7	1323.08	8	479.14	9	409.81
	Remainder	63	973.78	72	458.41	81	715.76

Mean squares due to Years and Stations which are significantly greater than the corresponding Remainder are indicated by asterisks.

**Exceeds 5% point.*

***Exceeds 1% point.*

Significant intra-monthly correlations in these percentages are again the main feature of Table XI, occurring in 10 of the 12 series of data examined. May precipitation at the central Alberta stations provided a marked exception to this general tendency, differences between the 10-year station averages quite overshadowing those between the 8-station monthly averages. For some reason, the percentage of the total precipitation occurring in amounts greater than 0.30 in. per day was, during the period studied, consistently greater at the western and northern stations in this district than at the southern and eastern ones. In southern Alberta in June differentiation between both years and stations was significant. The latter, however, was in this instance almost entirely attributable to the abnormally high percentages reported at High River, the 11-year average at this point being no less than 94.1%, as compared with a general average of 66.4% for the other nine stations of the group.

The intra-monthly correlations in the percentages show that in the districts concerned there were significant differences in the average intensity of precipitation during the specified months from year to year. In addition, the residual mean squares of Table XI reveal considerable irregular variation in this respect from point to point within each district during the same month. The absolute and relative standard deviations specifying the latter are given in Table XII. Of the three months studied, June, the month of maximum

TABLE XII

STATISTICS OF LOCAL VARIATION IN PERCENTAGE OF TOTAL MONTHLY RAIN RECEIVED IN AMOUNTS EXCEEDING 0.30 IN. PER DAY

District	Statistic	May	June	July
Central Alberta	Standard deviation of percentage	23	18	26
	S.D. as proportion of district mean percentage	.44	.30	.46
Southern Alberta	Standard deviation of percentage	27	20	29
	S.D. as proportion of district mean percentage	.50	.29	.51
Central Saskatchewan	Standard deviation of percentage	29	25	26
	S.D. as proportion of district mean percentage	.63	.45	.48
Southern Saskatchewan	Standard deviation of percentage	31	21	27
	S.D. as proportion of district mean percentage	.68	.34	.51

average precipitation, had the least local variation, both absolute and relative, in the percentage of the total rainfall received in daily amounts exceeding 0.30 in. The absolute standard deviation of the percentages was practically the same in all four districts for May and July, but in proportion to the mean the former month was more variable in central and southern Saskatchewan.

Qualitative variations of this nature in the incidence of precipitation may be of considerable importance in connection with the correlation between precipitation and crop yields; for, as a result of them, the effectiveness of the rainfall during the same interval in different seasons, or at different places during the same season, may be far from directly proportional to the total amounts recorded. They also have a bearing on the accuracy of determinations such as those by Yarnell (20) of rainfall intensity-frequency data for engineering purposes. Here the object was to estimate from the available observations the intensity of precipitation which may be expected to be exceeded only once in 20, 50, 100, etc., years on the average in different sections of the United States. As the number of years' observations at individual meteorological stations was limited, it was considered that a more accurate estimate of the intensity-frequency would result from pooling the records of a number of stations in the same region. Whilst this is undoubtedly so, it should not be overlooked that the gain in accuracy in each case will depend on the degree of correlation in the intensity of precipitation at the stations

thus treated. For example, if the rainfall at each of the individual stations comprising one group was totally independent, then 30 years' observations at each of five stations would provide as good a sample of the annual variation characteristic of the district as would 150 years' observations at a single station. If, however, there was intra-annual correlation in the intensity of rainfall at stations in the same district, the gain in accuracy resulting from the inclusion of additional stations would be lessened by an amount proportional to the degree of correlation. In the extreme case, in which the correlation was perfect, the inclusion of any number of stations would provide no more information concerning the variability to be expected in successive years than that yielded by the observations at a single point.

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BLACK CHAFF, A COMPOSITE DISEASE[1]

By W. A. F. Hagborg[2]

Abstract

A study was made of the etiology of wheat discolorations that resembled bacterial black chaff. Three distinct types were found. One of these was caused by *Phyt. translucens* f.sp. *undulosum*, the bacterial black chaff organism; another yielded *Alternaria* consistently on isolation; and a third, internodal melanism, appeared to be physiological in origin. *Phytomonas atrofaciens* was occasionally present in bacterial black chaff lesions.

Seed and seedling inoculation methods, unaccompanied by wounding, proved unsatisfactory for testing the pathogenicity of bacterial isolates derived from lesioned wheat plants, but inoculation accompanied by wounding of the young primary leaf, still enclosed in the coleoptile, proved to be a quick and effective method. Soil inoculation methods were ineffective. A method, involving a minimum of mechanical injury to the tissues, was developed for flooding the mesophyll of wheat leaves with a bacterial suspension.

Introduction

In the work of breeding rust-resistant varieties of wheat suitable for use in Western Canada, Goulden and Neatby (5) found that in many cases susceptibility to a melanistic disease, tentatively referred to as "black chaff", was inherited from the rust-resistant parents. The genetic linkage between rust-resistance and susceptibility to this disease appeared to be very close, although not complete. There was some doubt as to the identity of the disease, as the discolorations on some strains of wheat appeared never to produce bacterial exudate, while in the same year those on other strains of wheat produced abundant exudate. A need was felt for a better knowledge of the disease in order that the experimental error might be reduced when testing the susceptibility to it of strains and varieties of wheat. The present investigation was undertaken to gain more definite information concerning the etiology of the disease and to find a satisfactory method of reproducing it.

Historical Review of the Etiology of Black Chaff

A general review of the literature on black chaff has been made recently by Bamberg (1). The present review is concerned with only the etiology of the disease.

In 1916 Jones, Johnson, and Reddy (8) mentioned a disease on wheat very similar to the bacterial blight of barley which they (9) later described in detail.

Erwin F. Smith (12) in 1917 described a new disease of wheat that afterwards came to be known as "black chaff". He described and illustrated the field symptoms, and expressed the belief that the disease was of bacterial

[1] *Manuscript received August 27, 1936.*

Contribution No. 460 from the Division of Botany, Experimental Farms Branch, Department of Agriculture, Ottawa, Canada. The project was also supported by a Special Open Fellowship and a Research Assistantship in the University of Toronto, and a National Research Council Bursary. This paper constitutes part of a thesis submitted in conformity with the requirements or the degree of Doctor of Philosophy in the University of Toronto, in March, 1935.

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origin because of the association with it of the same bacterial organism in two successive years. In the following year, he (14) reported that the causal organism of black chaff of wheat was similar to *B. translucens* Jones, Johnson, and Reddy, and in 1919 he collaborated with Jones and Reddy (16) in describing the organism from wheat as *B. translucens* var. *undulosum*.

Jaczewski (7), in 1925, emphasized the desirability of finding the cause of pigmentation in every new variety of black pigmented wheat, because of the difficulty of distinguishing macroscopically between bacterial black chaff discoloration and natural pigmentation. This appears to be the first suggestion in the literature that pigmentation of purely physiological origin might be mistaken for bacterial black chaff.

Prissyajnyuk (11) in 1931 found bacterial black chaff in the Lower Volga region of Russia. He considered that the black pigmentation was a reaction of the plant against the organism, and suggested that possibly the same reaction could be brought about by purely external causes, such as light and temperature, independently of bacterial infection.

Two years later Broadfoot and Robertson (3) reported the occurrence in strains of Reward wheat of a type of pigmentation that appeared to be due entirely to hereditary color factors which, in a suitable environment, produced the discoloration.

Israilsky and Kazakova (6) isolated from black chaff an organism intermediate in physiology between *B. translucens* and *B. atrofaciens*, which they considered might be a variant of the former as it resembled that organism in cultural characters.

In the present year, Bamberg (1) reported the first comprehensive investigation of the disease. He found that black chaff is caused by *Bacterium translucens* var. *undulosum* and that the symptoms of the disease varied with different varieties and different environmental conditions. To the symptoms of the disease mentioned by earlier workers, he added another one, namely, discolorations on the internodes.

Nomenclature

The name "black chaff" was used by Smith (13) for the disease of wheat caused by *B. translucens* Jones, Johnson, and Reddy var. *undulosum* Smith, Jones, and Reddy, but he (15) also referred to it as "bacterial black chaff". Up to the present the former designation has been used most commonly. To the glume discoloration that they considered to be a purely physiological disease, Broadfoot and Robertson (3) applied the name "pseudo-black chaff". As will be shown later, there are at least two other diseases that fairly closely approximate in symptoms the disease originally described by Smith (12). All four of these diseases might be loosely referred to as black chaff. In order to prevent confusion, it is here proposed always to use the combination "bacterial black chaff" when referring specifically to the disease caused by *B. translucens* var. *undulosum*. Here, too, the generic name *Phytomonas* Bergey *et al* will be used. In conformity with Recommendation I of the

International Rules of Botanical Nomenclature adopted by the Fifth International Botanical Congress, 1930, the organism causing bacterial black chaff is a *forma specialis* of *Phytomonas translucens* and is therefore designated as *Phyt. translucens* f.sp. *undulosum*.

Sources of Material

Each year of the investigation (1931–1934) specimens were collected in the cereal nursery of the Dominion Rust Research Laboratory and during surveys of the agricultural areas of Manitoba. The specimens studied included all types of dark discoloration of wheat heads that could not, from macroscopic symptoms, be attributed definitely to *Septoria nodorum* Berk., *Phyt. atrofaciens* McC., or *Helminthosporium sativum* P.K. & B. In fact, the material examined included all the range of discolorations which had been identified tentatively as "black chaff" previous to the commencement of the present investigation.

Etiology

Association of Bacteria with the Diseased Condition

A microscopical examination was made to ascertain whether or not some organism was constantly associated with the diseased condition of the various tissues. Smear mounts were found most satisfactory. A small quantity of the diseased tissue was teased out in a drop of distilled water on a No. 1 cover-slip. The mount was fixed by heat and stained with Ziehl's carbol fuchsin. When the material was taken from fresh water-soaked lesions, rod-shaped bacteria of the dimensions of *Phytomonas translucens* were always present in myriads. Similarly, when the material examined was taken from dry specimens of dark linear glume lesions, such as those described and illustrated by Smith (12) for bacterial black chaff, the bacteria could always be found in large numbers; but they could not be found abundantly in other dark glume lesions of a less sharply delimited type. The latter type of discoloration was associated with sterility of the florets.

Isolation

Isolation of a causal organism from diseased specimens was attempted in as many cases as possible in order to obtain a maximum of information on the etiology of the dark discolorations. From lesions of the type that bore bacteria in large numbers, it was found possible to isolate an organism that resembled *Phyt. translucens* f.sp. *undulosum* in color and in colony type. In the present study, the organism was first isolated in 1931 from young lesions on wheat plants collected at Souris, Man. In 1932 it was obtained from two varieties of naturally infected wheat growing in the experimental plots at Winnipeg. It was quite prevalent in 1933, for it was isolated from material collected in 20 different localities. In 1934 it was found at only two points, although as thorough a survey was made in that year as in 1933. It was as prevalent in Manitoba in 1935 as in 1933.

In the earlier attempts to isolate the black chaff organism, mercuric chloride (0.1% aqueous solution) was used to surface-sterilize the diseased tissue before plating it on the surface of nutrient media. This method proved unsatisfactory, because it was found that *Phyt. translucens* f.sp. *undulosum* is very sensitive to the germicidal action of mercuric chloride. Several other methods of isolation were tried, with the result that the following one was adopted.

A small portion (about 3 sq. mm.) of the lesioned tissue was cut out with a flamed pair of scissors and dipped in 95% alcohol before being placed for 1 minute in 0.1% mercuric chloride solution. It was then washed in 10 cc. of sterile distilled water, transferred to a sterile Petri dish, and torn apart aseptically to expose the live bacteria within the tissue. Four dilution plates of beef-peptone agar were poured from the torn tissue. The plates were incubated at 26° C. for 10 days, following which they were examined with a hand lens in oblique transmitted light.

In sub-culturing from a set of isolation plates, from one to three transfers were made from colonies of the predominating type. Where two or more types occurred in abundance, additional sub-cultures were made to include these types.

In the majority of cases, the cultural characters of the isolates thus obtained conformed to those described for *Phyt. translucens* f.sp. *undulosum*.

A white bacterial organism occurred rarely in the isolation plates made from collections of black chaff. In three collections both it and the bacterial black chaff organism occurred together in the diseased tissues, as shown by the fact that they were both present in large numbers in the same dilution plates. The white organism resembled *Phytomonas atrofaciens* in cultural characters except that it did not produce a green pigment in beef-peptone agar (Difco Bacto Nutrient Agar). However, it produced a green fluorescent pigment readily in the modified Sullivan's solution recommended by Clara (4) for exhibiting green fluorescence.

Some collections failed to yield either of the above-mentioned bacterial pathogens but from them was obtained a species of *Alternaria* that resembled *A. tenuis*. From some collections no pathogen could be obtained.

All of the isolates were tested individually for pathogenicity by the inoculation of wheat seedlings.

Production of Symptoms by Artificial Inoculation

In the early stages of the investigation, no satisfactory method was known to test the pathogenicity of a large number of isolates. One isolate, which conformed to the cultural description of *Phyt. translucens* f.sp. *undulosum* and which had been found by the inoculation of sprouted seed to be pathogenic, was used in developing a method for testing the pathogenicity of the isolates. Several methods of seedling inoculation which are discussed briefly below were tried and one of these, the coleoptile-piercing method, proved to be particularly useful. It was used to test the pathogenicity of several hundred

isolates from disease lesions in order to eliminate the cultures that were non-pathogenic and to ascertain whether pathogens other than *Phyt. translucens* f.sp. *undulosum* were associated with lesions resembling those of black chaff.

It was found that the organism that was isolated repeatedly from typical bacterial black chaff produced water-soaked lesions on wheat seedlings when inoculated by this method. The organism was also found to be pathogenic in adult plants, causing lesions in leaves, peduncles, and heads. Infections were obtained ranging from a trace to a severity that caused premature death of the whole head.

The white organism, when introduced into wheat seedlings by wounding the young primary leaf with a needle dipped in inoculum, did not produce water-soaked areas, but caused the margins of the wounds to turn brown. When used to inoculate wheat heads, it produced typical basal glume rot such as is caused by *Phyt. atrofaciens*.

A mixture of spores and mycelium of the species of *Alternaria* mentioned earlier was used to inoculate heads of wheat that were in the flowering stage and were growing under greenhouse conditions in late winter at Winnipeg. The strain H-44-24 × Marquis (R.L. 590,) was used, as it had proved to be particularly susceptible under field conditions to the development of head discoloration of the type from which *Alternaria* could be isolated consistently. The inoculum was inserted in aqueous suspension between the glumes, and the plants were held in moist chambers for a period of 48 hours before being placed on a greenhouse bench. Discoloration in the empty glumes and the lemmas resulted but the controls were free from discoloration. Sterility was common in both the inoculated and uninoculated plants.

Production of Discoloration by an Unfavorable Environment

It has been mentioned above that from some collections of discolored specimens no pathogen could be isolated. In ten out of eleven collections of discolored internodes no pathogen was found, although non-pathogenic bacteria were sometimes abundant in the isolation plates. In only one of the eleven collections was a pathogen present, and it proved to be identical in cultural characters with the white bacterial organism referred to above. The fact that in ten cases out of eleven no pathogen was isolated from discolored internodes suggested the possibility that the discolored tissue was in a degenerate physiological condition and constituted a good infection court for various inocuous bacteria. Results of experiments on black chaff infection in adult plants favoured this view. In the course of such experiments it was discovered that a black discoloration, which seemed to be of non-parasitic origin, occurred in certain varieties of wheat. Plants placed in moist chambers at a high temperature for 36 hr. subsequently developed discoloration, while other plants of the same population left on the greenhouse bench developed no discoloration.

To study this type of discoloration a susceptible and a non-susceptible variety were subjected to environmental conditions conducive to the develop-

ment of the discoloration. Three lots of Pentad × Marquis wheat (R.L. 723) and three lots of Marquis were held in moist chambers at about 25° C., one lot of each variety being held for a period of 36 hr., another for 48 hr., and the third for 60 hr. The various lots were placed in the moist chambers at such times as to permit all plants to be removed from them at one time. When removed from the moist chambers, the plants were placed in a greenhouse kept at about 25° C. Twelve days later the plants were examined for darkening of the tissues. The results of the examination are shown in Table I. A large percentage of internodes, peduncles, and rachides, of R.L. 723, but not of Marquis, became discolored, but none of the glumes in either variety was affected. The younger culms were definitely less susceptible to discoloration than were the older ones.

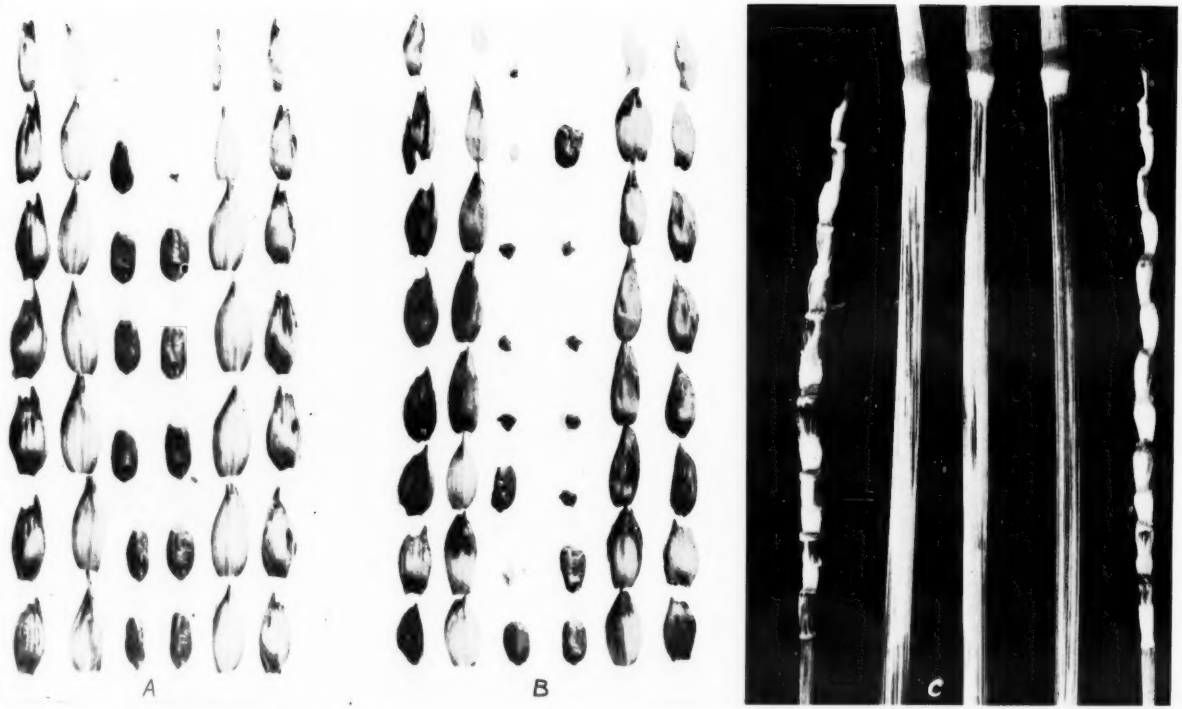
TABLE I

EFFECT OF EXPOSURE IN MOIST CHAMBERS AT 25° C. FOR VARIOUS LENGTHS OF TIME, ON THE SUBSEQUENT DEVELOPMENT OF DISCOLORATION IN TWO VARIETIES OF WHEAT

Variety	Length of exposure, hr.	Total culms	Number of discolored plant parts			
			Internodes	Peduncles	Rachides	Glumes
Marquis	36	15	0	0	0	0
	48	17	0	0	0	0
	60	14	0	0	0	0
R.L. 723	36	21	14	17	17	0
	48	17	12	11	12	0
	60	14	6	7	7	0

Isolation was attempted from six of the discolored areas, but in no case could a pathogen be recovered. It would appear that the pigmentation of the tissues was directly attributable to enclosure in the moist chambers, as no discoloration appeared on plants kept at the same temperature under normal greenhouse conditions.

This disease, which may be referred to as internodal melanism, seems to be of different genetic origin from the pseudo-black chaff described by Broadfoot and Robertson. They suggested that the symptoms were due to hereditary color factors, which, under suitable light intensity, produced dark pigmented areas on the glumes. In internodal melanism the glumes do not become discolored, while in the pseudo-black chaff the glumes are the only parts that do become pigmented. Specimens that were apparently pseudo-black chaff have been collected at Winnipeg both on Reward and on strains of hybrid origin that had Reward as one parent. Attempts to isolate an organism from pseudo-black chaff material yielded no pathogen, a result in keeping with Broadfoot and Robertson's findings. Internodal melanism appears to be distinct, too, from the definitely reddish pigmentation that sometimes occurs in the internodes, leaf-sheaths, and leaves of some varieties of wheat, such as Garnet. The pigment occurring in such reddened tissues is quite soluble



A. Bacterial black chaff. Dissected spikelets from one side of wheat head showing glumes (the two outer rows) with discoloration and lemmas (the inside rows) with little or no symptoms of the disease. The sterility of the apical florets is probably not due to bacterial black chaff. B. Discoloration by Alternaria. Dissected spikelets from one side of a wheat head showing discoloration both of glumes (the two outer rows) and lemmas (the inside rows). The cause of the pronounced sterility associated with this discoloration has not been determined. C. Internodal melanism. Rachides and stems of wheat plants showing the dark pigmentation.

PLATE I

in water, being red in acid solution and green in alkaline. It is, therefore, distinct from the pigment in internodal melanism, which is insoluble in water and in many other solvents.

Re-isolation and Cultural Comparisons

The organism that was isolated from the majority of field collections, *viz.*, *Phyt. translucens* f.sp. *undulosum*, was re-isolated repeatedly from artificially infected wheat seedlings and adult plants. The re-isolated cultures were found to produce symptoms similar to those produced by the original isolates. They were compared with the original isolates also on culture media and found to be identical with them.

Similarly, the white organism was re-isolated and compared with original isolates and found identical with them. It was also compared with isolates from field collections of what appeared to be typical basal glume rot and found similar to them in the symptoms produced following head inoculations, and in cultural characters. No green pigment was formed in beef-peptone agar by any of these cultures.

Cultures of *Alternaria* were re-isolated from the heads of wheat that became infected following artificial inoculation with the mixed suspension of Alternaria inoculum referred to above.

It can be concluded from the above studies that, while *Phyt. translucens* f.sp. *undulosum* was more or less common in Manitoba during the years of the investigation, it was not the cause of all the discolorations tentatively referred to as "black chaff" at the beginning of this investigation.

Characteristics of the Discolorations Studied

Although the study has shown that more than one cause was responsible for the discolorations, from casual inspection the discolorations appeared very similar. Close examination, however, showed definite differences between the discolorations arising from different causes. The collections from which *Phyt. translucens* f.sp. *undulosum* was isolated were characterized by a sharply delimited discoloration, chiefly confined to the chlorenchyma of the empty glumes, but sometimes also affecting the distal ends of the lemmas and the upper part of the peduncles (Plate I, A). The kernels were sometimes plump, but when the attack was heavy they were shrivelled.

In the collections from which only *Alternaria* was isolated, the margins of the discolored areas were not sharply delimited and the discoloration was diffused throughout the tissues, chiefly of the lemmas (Plate I, B). The florets were often sterile, and when sterile the ovary and stamens were frequently overgrown with mycelium.

In the type of discoloration referred to above as internodal melanism only the rachides, peduncles, and stems proper (not leaf sheaths) were affected (Plate I, C). Discoloration occurred chiefly in the chlorenchyma but vascular tissues and ground parenchyma were also sometimes black-pigmented. The margins of the discolored areas were sharply delimited. Younger culms were free from this discoloration.

Inoculation Studies of Bacterial Black Chaff

Several authors have stated that they obtained infection following artificial inoculation with the bacterial black chaff organism. Jones, Johnson, and Reddy (9), in describing the bacterial blight of barley, stated that they isolated from wheat an organism similar to the barley organism. With it they reproduced the disease on wheat by artificial inoculation. They did not describe the method. Smith (13) reported that he obtained infections on both spikelets and seedlings, but he did not say by what method of inoculation. Braun (2) obtained infection on seedlings by planting infected winter wheat and by inoculating seed with a suspension of the organism. Verwoerd (18) described a method of seedling inoculation. He sprayed seven-day-old seedlings of Hope and Kanred wheat with a heavy suspension of the organism in water. He incubated the plants at 25° C. in a moist chamber for 48 hr., and then placed them in the greenhouse, where they were kept moist by being sprayed with distilled water several times a day. This method gave results varying from "negative" to "maximum". No percentages of infection were given.

In his recent paper Bamberg (1) reported trying three different methods of inoculation *viz.*, (i) spraying with a bacterial suspension, (ii) rubbing the suspension on the leaves with the fingers and (iii) forcing the inoculum into the leaf roll of young plants or into the boot of older plants with a hypodermic syringe. He found that the third method was the most successful, the first two methods giving unsatisfactory results.

In the present investigation several methods of inoculation were tried to determine which one would give the most satisfactory results. These included different ways of inoculating seed, soil, seedlings, and mature plants with pure cultures of *Phyt. translucens* f.sp. *undulosum* isolated in this study.

(a) Seed Inoculations

When unsprouted uninjured seed was inoculated with a suspension of the organism in water, dried, and planted, a small percentage of the resulting seedlings showed infection. Sprouted seed inoculated in the same manner gave rise to a somewhat higher percentage of infected seedlings, but, when the unsprouted seed was injured by pricking the pericarp above the embryo with a sharp flamed needle before inoculation, a larger percentage of infected seedlings was obtained. Increasing the concentration of inoculum by smearing the seed with the organism before immersing it in the suspension still further

TABLE II

Summary of results of seed inoculation tests

Seed condition	State of inoculum	Location	Number of seedlings	Diseased seedlings, %
Uninjured, unsprouted	Suspension	Field	1079	13
Uninjured, unsprouted	Suspension	Greenhouse	139	14
Uninjured, sprouted	Suspension	Greenhouse	129	34
Injured, unsprouted	Suspension	Greenhouse	129	49
Injured, unsprouted	Bacterial slime	Greenhouse	45	71
Injured, unsprouted	Bacterial slime and suspension	Greenhouse	62	81

increased the percentage of infected seedlings. The results of the experiments with seed inoculation are summarized in Table II. While a fairly high percentage of infection could be obtained by inoculating injured seed, the method was tedious, and injury was accompanied by a sharp reduction in the percentage of germination. It would thus appear that seed-inoculation methods cannot be considered very satisfactory for testing the pathogenicity of cultures.

(b) Soil Inoculations

Soil inoculation was found to be ineffective both when the organism was added to sterilized soil in pots and seed planted in it, and when inoculated soil was added with the seed to the rows in a field test.

(c) Seedling Inoculations

Spraying or smearing uninjured seedlings with inoculum before placing them in moist chambers for 48 hr. resulted in a small percentage of infection, but when the leaves were injured by pricking with a needle or by rubbing with the fingers to break off trichomes, large percentages of infection resulted. The following method was found to be most satisfactory for use in testing the pathogenicity of isolates. Wheat was sown at a depth of $\frac{1}{4}$ in. in pots of loam soil. The pots were watered and set in a moist chamber until the coleoptiles reached a height of from 7 to 15 mm. above the soil. A flamed, sharp nichrome needle was dipped into the inoculum and then used to pierce the coleoptiles and enclosed primary leaves. The pots were then kept in a greenhouse at a temperature of about 25° C. Ten days after inoculation, the plants were examined for infection. This method resulted in 100% of the plants becoming infected whenever a culture of *Phyt. translucens* f.sp. *undulosum* was used as inoculum.

When the mesophyll of seedling leaves was flooded with a dilute filtered* suspension of the organism, abundant infection resulted in each of 39 leaves so inoculated. The mesophyll was flooded by means of a glass tube drawn to an outside diameter of 90–135μ and attached by means of liquid solder to a hypodermic needle fitting. The fitting was attached to a hypodermic syringe in the usual fashion. To inoculate a leaf a shallow rupture was made in the lower epidermis adjacent to the mid-vein by means of a sharp metal needle. The glass needle was inserted through the opening and forced into the mesophyll until the end of the needle was about 7 mm. from the rupture in the epidermis. Compression of the syringe flooded about a square centimeter of the mesophyll, giving it a dark green water-soaked appearance, which became normal in appearance within a few minutes. Thirty-nine seedlings were thus inoculated. After 13 days minute water-soaked points began to appear in the inoculated areas. By the fifteenth day infection was visible in every leaf that had been inoculated.

In comparison with the method in which the coleoptiles and first leaves were punctured with a needle dipped in inoculum, the injection method had a much longer incubation period. The difference, from five to eight days,

*No. 1 Whatman Filter Paper.

was probably attributable to the greater initial amount of inoculum introduced at each inoculation point by the former method. In the needle-puncture method, a mass of bacteria were introduced into the wound, while in the mesophyll-injection method, the bacteria were introduced as a dilute filtered suspension and would therefore have to commence the attack as individuals or in very small groups. In subsequent trials of the injection method it was found that the incubation period could be reduced to as little as two days by increasing the concentration of the suspension of bacteria injected.

(d) Adult Plant Inoculations

As incubation in moist chambers at a temperature optimal for the bacterial black chaff organism resulted in abundant discoloration of the type which has been referred to above as "internodal melanism", a method of inoculation, which overcame the necessity of incubation in moist chambers, was used. Plants were inoculated by piercing their leaf sheaths with a hypodermic needle and injecting a broth culture of *Phyt. translucens* f. sp. *undulosum*. This method has been widely used for the inoculation of adult cereal plants with uredospores of stem rust since it was described by Zehner and Humphrey (19). Bamberg (1) made use of it in his recent work on black chaff.

In this experiment 19 culms of a susceptible strain of wheat were used. At the time of inoculation 2 were in head, 4 in the shot-blade stage, and 13 in the leaf-roll stage. The inoculum was developed in beef-peptone broth and injected under the leaf-sheaths by means of a sterilized hypodermic syringe fitted with a fine steel needle. After inoculation the plants were placed on a bench in the greenhouse where the temperature underwent the usual daily fluctuations.

Of the 13 infected culms 8 had infections on the glumes, 4 on the awns, 2 on the rachides, 4 on the necks, and 2 on the leaves. Some culms had infections in two or more of these parts. The infections ranged from heavy to light. No internodal infections were found.

In the younger stages of infection the lesions were water-soaked but, between the fourteenth and twenty-first day after inoculation, most of them had turned dark brown or black.

Two similar experiments, in which an agar culture of the organism suspended in sterile distilled water was used as inoculum, gave infection percentages of 57.5 and 59. This method has given moderately satisfactory results under field conditions.

Discussion

In his paper entitled, "A New Disease of Wheat", Smith (12) accurately described and illustrated the symptoms of bacterial black chaff. His photographs show well that the sharply delimited lesions occur chiefly in the chlorenchyma, thereby giving the glume a striped appearance with fusion of the stripes near its apex. He said nothing about discoloration of the internodes nor did he illustrate any stem lesions except those immediately below the head. When, however, at Winnipeg, internodal discolorations were found associated

with head symptoms of bacterial black chaff in strains of wheat of hybrid origin, it was tentatively assumed that such discolorations were additional symptoms of bacterial black chaff. From the present study it appears that this assumption was ill-founded and that the discoloration of the internodes (internodal melanism) is a physiological disorder characteristic of certain strains and varieties of wheat. In view of the regularity with which *Phyt. translucens* f.sp. *undulosum* can be isolated from bacterial black chaff lesions, failure to isolate it from any of the eleven collections of internodal melanism is good evidence that such discolorations are not caused by the bacterial black chaff organism. An extensive isolation study, to ascertain whether the organism is sometimes associated with such lesions, has been commenced.

The dark discoloration associated with bacterial black chaff is apparently not produced directly by the organism. At any rate, no black pigment is produced by *Phyt. translucens* f.sp. *undulosum* when grown in artificial culture, and, under greenhouse conditions, bacterial black chaff lesions do not turn black until several days after the maximum areas of infection have developed. Although there is no proof at present of the chemical nature of the pigment in lesions of bacterial black chaff, the similarity in color between it and the pigment in the discolored internodes suggests that the pigments are similar in nature. Besides, both pigments are highly insoluble in a large number of solvents. Stapp (17), in generalizing on the symptoms of bacterial diseases in plants, stated that increased oxidase activity sometimes ensues from disturbance in the balance of oxidizing and reducing processes in otherwise healthy cells, manifesting itself in dark discolorations. Such is probably the case in bacterial black chaff. Lewicki (10) made a detailed study of pigmentation in naturally pigmented wheats. He found that the presence of black pigmentation is due to the oxidation of catechol tannins, the reaction being catalyzed by oxidases. He considered that the pigmentation reaction gives rise to increased respiratory activity due to the great ability of the tannins to absorb oxygen. Whether or not the same chemical reactions are involved in bacterial black chaff and internodal melanism as in naturally black-chaffed wheats is not known, but it seems probable that in the former cases as in the latter the black pigmentation is due to the oxidation of a chromogen.

The relation between pseudo-black chaff and internodal melanism requires further clarification. If it is assumed that the pigment in both arises as the result of the same chemical reaction, then the failure of the glumes of R.L. 723 to develop a black pigmentation under the same conditions which resulted in black pigmentation in the internodes must have been due to improper concentration in the glumes of one or more of the reacting substances. The concentration of these substances in different plant parts very probably varies with the variety and it is conceivable that the reacting substances may be present in proper concentration only in the glumes of one variety and only in the internodes of another variety when both varieties are grown under the same conditions. The pigmentation would then manifest itself as two types which could be distinct in inheritance although the pigment was chemically

the same in both. Whether or not in pseudo-black chaff and internodal melanism the pigments are identical is not known, but the information so far available suggests that the two discolorations are distinct in inheritance. For example, some strains of Reward wheat develop pseudo-black chaff but apparently cannot be induced to develop internodal melanism, while some varieties, such as Hope, develop internodal melanism but apparently not pseudo-black chaff. On the other hand, both discolorations will develop in a pure line selection of Renown, *viz.*, R.L. 716-1, which originated in a cross between Reward and H-44-24 and therefore possibly inherited susceptibility to one of these discolorations from each parent. However, until a study is made of a family of segregates following a cross between two varieties, one of which is susceptible to pseudo-black chaff but not to internodal melanism and the other susceptible to internodal melanism but not to pseudo-black chaff, the relation between these two physiological diseases will not be well understood. Such a study should be accompanied by a detailed investigation of the influence of environmental factors on the development of pigmentation, as the possibility exists that the metabolism of even a variety such as Hope may be altered sufficiently to induce black pigment production in the glumes.

In conclusion it may be pointed out that the discovery that the discolorations formerly included under the designation "black chaff" are of multiple origin has aided an understanding of several formerly irreconcilable facts. One of these was that certain varieties in some years developed very heavy discoloration of the internodes but their glumes were quite free from discoloration, while the glumes of other varieties were heavily discolored but the internodes were relatively free from it. These reactions were difficult to understand until both internodal melanism and bacterial black chaff were known to be present.

Acknowledgments

The writer is indebted to Dr. D. L. Bailey, Associate Professor in the Department of Botany of the University of Toronto, and to Dr. J. H. Craigie, Officer-in-charge of the Dominion Rust Research Laboratory, for their counsel in the execution of this investigation. He is also indebted to Mr. M. Timonin for translation of the papers by Jaczewski and Prissyajnyuk.

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Canadian Journal of Research

Issued by THE NATIONAL RESEARCH COUNCIL OF CANADA

VOL. 14, SEC. D. SEPTEMBER, 1936 NUMBER 9

THE BLACKFLIES OF EASTERN CANADA (SIMULIIDAE, DIPTERA).[1] PART I.

BY C. R. TWINN[2]

Abstract

Twenty-three species and one variety belonging to three subgenera of the family Simuliidae are recorded and described. Of these, twelve species and the variety are new to science. Only two of the remaining eleven species of other authors have been previously recorded in Eastern Canada; two others, originally described in Europe, are recorded in North America for the first time, and the hitherto unknown male of a fifth species is described. The adult forms and the pupae and cocoons of these species are described, and the genitalia of both sexes of flies are figured. In addition, notes on the habitats, distribution, species associations, and similar information of value in identifying the species are given. Keys to the subgenera and species, including both sexes of adults and the pupae are an important feature.

Introduction

Blackflies have long been recognized as among the worst bloodsucking insect pests affecting wild and domestic animals and man, in many parts of the world, and the literature contains numerous references to their serious depredations. Among the most famous and spectacular are the outbreaks of the buffalo or turkey gnat, *Simulium pecuarum* Riley, in the lower Mississippi valley of the United States, and of the Golubatz fly, *S. columbaczense* Schoenbauer, in parts of south-eastern Europe. The latter species was reported to have caused the deaths of many thousands of wild and domestic animals in Rumania in 1923. In recent years, blackflies have been implicated in the transmission of disease-producing organisms, and it is probable that further studies will prove them to be of greater importance in this connection than is at present known. In 1926, Blacklock (1) discovered that the intermediate host of *Onchocerca volvulus* Leuckart, a filarial worm causing disease in man in West Africa and Uganda, is the blackfly, *Simulium damnosum* Theo. Another filarial worm, *O. caecutiens* Brumpt, possibly only a variety of *O. volvulus*, which infests man in Mexico and Central America, was shown by Hoffman (22), in 1930, to pass its intermediate stages in the blackfly, *S. mooseri* Dampf; since then certain other species of blackflies have also been proved to be vectors of the organism. O'Roke (34)demonstrated that a serious protozoon blood parasite of ducks, *Leucocytozoon anatis* Wickware, prevalent

[1] *Manuscript received July 11, 1936.*
Contribution from the Entomological Branch, Department of Agriculture, Ottawa. This paper was presented at McGill University, Montreal, in partial fulfilment of the requirements for the degree of Master of Science.

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in North America, passes the sexual stage of its life cycle in the blackfly, *S. venustum* Say, transmission in nature being effected by the bite of the fly. Both this fly and the disease are widespread in Canada, as I have reported elsewhere (55).

The published information on the blackflies of Canada, especially of Eastern Canada, is very meagre. The late Eric Hearle, in 1932, prepared (20) a useful annotated list of the blackflies of British Columbia in which he included twenty species, two of which were new. Twinn (55), in 1933, published a short article on the general biology and distribution of *Simulium venustum* Say, in Canada. In 1927, Dyar and Shannon (5) published a revision of the Simuliidae of North America. Only two of the 47 species included were shown as occurring in Eastern Canada.

Scope of Work

The present paper includes twenty-three species and one variety belonging to three subgenera of the family Simuliidae. Twelve of these species and the variety are described as new to science. Of the remaining eleven species of other authors, only two, *venustum* Say and *johannseni* (Hart), have been recorded previously in Eastern Canada; two, *subexcisum* Edw., and *latipes* Mgn., originally described in Europe, are recorded in North America for the first time; and the hitherto unknown male of *mutatum* (Mall.) is described, and the pupa associated with the adult forms.

The treatment followed throughout is essentially taxonomic. The adult forms are described, and brief descriptions of the pupae and cocoons are given; also notes on the habitats, distribution, species associations, and similar information of value in segregating and determining the species. Keys to the subgenera and species are presented; the latter include both sexes of adults and the pupae and cocoons, and should prove to be a valuable feature.

It is hoped that an opportunity will later arise to extend the study to include adequate treatment of the immature stages, and the biology of the various species. Much material and information have already been brought together toward this end.

Material and Methods of Study

The study is based on material collected in the territory surrounding Ottawa, in Ontario and Quebec, known as the Ottawa district, and on specimens from other parts of Eastern Canada, including Baffin Island. However, the number of specimens in the National Collection, or received from collectors in this region was small, and therefore the work has been carried out largely with material collected and reared by me in the Ottawa district. This work was done with the permission of the Dominion Entomologist. Numerous collections of immature stages were made prior to 1935, but the systematic examination of breeding places, and rearing of adults from pupae was done, for the most part, during the spring and summer of 1935.

In the course of the investigation (necessarily restricted by other duties), five rivers including the Ottawa, Rideau, Blanche, Jock and Mississippi, and sixteen permanent, semi-permanent and temporary streams and rills, all within a few miles of Ottawa, were visited and examined at definite points, at intervals from late April to the end of September. During these visits notes were taken on the seasonal character of the water bodies, their rate of flow, temperature, and other data; more than 300 alcohol collections were made of the blackfly stages found, and live pupae were placed on moist cotton in stoppered vials for rearing, all being associated by means of experimental numbers.

The adult flies were reared from the pupae, after being roughly segregated by species under the low power objective of the microscope, by means of the number, arrangement and character of the filaments comprising the respiratory organs, and the nature of the cocoons. When *Simulium* pupae are kept moist (not wet) they will complete their development even though removed from their natural habitat, and will give rise to imagines, which may be transferred to dry vials by taking advantage of the positive phototropic responses of the flies.

Rearing the adult flies in this manner is undoubtedly the most satisfactory method of securing material for a taxonomic study of the Simuliidae. By this method both sexes are secured in excellent condition, whereas if one confines his activities to collecting with a net he usually secures only the females, and these often in poor condition. Moreover, the rearing method definitely connects the adults with their immature stages, concerning which there has been much confusion, and establishes the nature and location of the breeding places. When the pupae are known, it is comparatively simple to identify the larvae, this being accomplished merely by dissecting out and examining the filaments in the pupal respiratory histoblasts, in the prothorax of the mature larva.

A satisfactory method of rearing adults from pupae consists of using glass vials $1\frac{1}{4} \times 6$ in., placed on their sides; in these, a narrow strip of cotton batting, wet, but with the surplus water removed, is inserted lengthwise along the glass, and the pupae gently placed on it. A similar vial containing a strip of dry blotting paper is placed with its mouth against that of the vial containing the pupae. The two vials are then wrapped in paper in this position, the paper held in place by rubber bands and completely covering the vial containing the pupae, but leaving two or three inches of the emergence vial uncovered. When the flies emerge they are attracted by the light into the emergence tube, where the blotting paper absorbs any surplus moisture and provides them with a resting place. The flies were usually left for 18–24 hours after emergence to allow the body integument to harden before pinning. The pupal skins and cocoons were preserved in alcohol-glycerine solution under the same experimental number as the pinned adults; when the latter were numerous some of them were also preserved with the skins.

The Characters of the Group

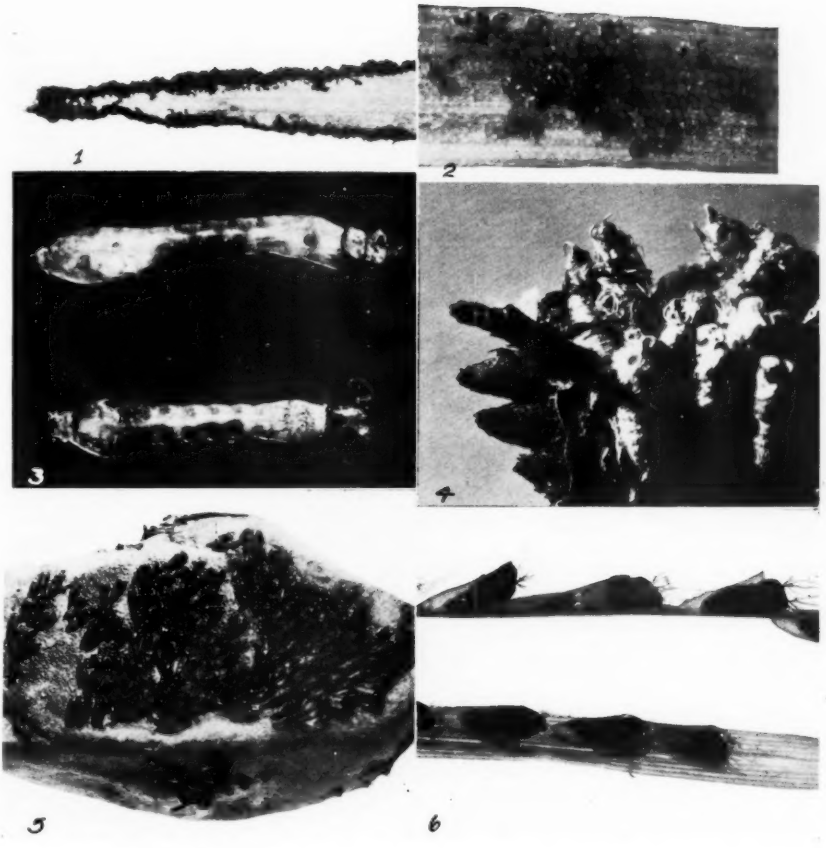
Blackflies are small, compact, stoutly-built flies, with the thorax greatly developed and curiously arched. The wings are broad with the anterior veins thickened, and the others indistinct; the legs are short and strong; the abdomen is nine-segmented. The antennae are short and typically eleven-jointed, but sometimes ten or nine-jointed; the palpi are four-jointed. The eyes are large and holoptic in the male, dichoptic in the female, the upper facets of the male much larger than the lower*; ocelli are absent. The mouthparts of both sexes are adapted for piercing, but only the females suck blood. The immature stages develop in running water. Illustrations of the eggs will be found in Plate I, Figs. 1, 2; of the larvae, in Plate I, Fig. 3; of the pupae, in Plate I, Figs. 4, 5, 6. Puri (41) has published an excellent account of the life history and structure of the early stages of Simuliidae; Johannsen (23, 24), Pomeroy (38), Edwards (7) and others, have also made important contributions to this interesting subject.

Explanatory and illustrated accounts of the wing venation and other external characters of the Simuliidae, a knowledge of which is necessary for students of the group, will be found in the works of Malloch (29), Edwards (6 and 8), Pomeroy (38) and Dyar and Shannon (5), and need not be repeated here. Two terms used in the following keys and descriptions to describe certain important tarsal characters were adopted by Edwards (8, p. 122) from Enderlein. To prevent possible confusion, Edwards' definition of these terms is given as follows: "(1) *Pedisulcus*, the dorsal incision near the base of the second segment of the hind tarsi; and (2) *Calcipala*, the flattened projection at the tip of the first segment (basitarsus) of the hind tarsi, projecting beyond the base of the second segment on the outer side".

In the taxonomic study of the material brought together as already outlined, the genitalia of both sexes were studied, in addition to external characters and the characters of the pupae and cocoons. This work entailed a great deal of delicate and painstaking dissection work under the binocular microscope, and the making of more than 300 permanent microscopic preparations mounted in euparal on slides. Furthermore, 93 separate drawings illustrating the genital structures were made with the aid of a camera lucida, and are included in this paper. These were all drawn to the same scale and reveal quite striking variations in the size of the genitalia of the different species, as well as in form.

The use of the male genitalia in taxonomic studies of the Simuliidae is comparatively recent. According to Edwards (6, p. 23) and Gibbins (17, p. 317) Lundstrom (27), in 1911, was the first to pay attention to these structures, in an account of the Finnish species, but he did not study them closely and his drawings were not sufficiently detailed. Edwards (6) made use of them in 1915, in describing the British species of *Simulium*, and also in a paper (8)

* *Edwards (8) described two South American species in which the eyes of the males are dichoptic and all the facets small.*



1. *Egg masses of S. vittatum Zett., on submerged leaf; about natural size. 2. Egg mass of S. venustum Say. ×11. 3. Mature larvae of S. vittatum Zett., lateral and dorsal views; about six times natural size. 4. Pupae and emerging adult of S. lascivum n. sp. about three times natural size. 5. Cocoons and pupal skins of S. venustum Say on stone; about natural size. 6. Pupae and cocoons of S. vittatum Zett.; about 3¼ times natural size.*

on South American species, published in 1931. Among American authors, Pomeroy (38) drew attention, in 1916, to the remarkably constant specific characters exhibited by the genitalia of the males; Cameron (2) made use of them, in 1922, in describing the cattle-infesting *S. simile* (= *S. arcticum* Mall.), and Dyar and Shannon (5) largely based their descriptions on the genitalia of the males and females in their revision of the North American species of the family. The last named authors appear to have been the first to use the female terminalia in this connection. Gibbins (15) also described and figured the genitalia of both sexes in a paper on Ethiopian Simuliidae published in 1934.

In describing the genitalia of the species of Eastern Canada included in the present study, I have followed the terminology of Dyar and Shannon. Since the major part of this work was done, a paper by Gibbins (17) on the male terminalia has come to hand. In this he states that the organ situated between the coxites (side-pieces) and referred to by Pomeroy (38), Dyar and Shannon (5), and herein, as the adminiculum is actually the anterior part of the phallosome; the adminiculum arms are the posterior part of that organ.

Classification

Until 1914, the family Simuliidae was considered to consist of only the genus *Simulium*. In that year, Malloch (29) in his study of American blackflies adopted the name *Prosimulium* Roubaud in a generic sense, and set up the new genus *Parasimulium*. Enderlein, in 1921 (10), recognized seventeen genera, and, in 1930 (11), increased this to thirty. Edwards, in 1931 (8), after a study of more than 120 species of Simuliidae in the British Museum, concluded that, with the exception of *Parasimulium*, none of the divisions recognized by other authors should be admitted as full genera, and, at most, seven of them as subgenera: namely, *Prosimulium*, *Morops*, *Gigantodax*, *Austrosimulium*, *Cnephia*, *Eusimulium* and *Simulium*.

The present study of Canadian species has led me to follow Edwards in recognizing as genera only *Parasimulium* and *Simulium*, admitting the others as subgenera of the latter. The genus *Parasimulium* has not been recorded in Canada. Only a single female specimen, of one species, *P. furcatum* Malloch, is known; this was collected in Humboldt County, California, on June 9, 1903, by H. S. Barber.

Three subgenera are represented among the species dealt with here: namely, *Prosimulium* Roubaud, *Eusimulium* Roubaud and *Simulium* Latreille. I have followed Dyar and Shannon (5, p. 12) in placing a fourth, *Cnephia* Enderlein, with the subgenus *Eusimulium*. Three of the species: *mutatum*, *boreale* and *lascivum* have characters of *Cnephia* as outlined by Edwards (8, p. 144); however, to admit it as a subgenus would result in separating the two closely related species, *boreale* and *baffinense*. The characters used to define the subgenera included in this paper are given in the following key.

Key to the Subgenera of *Simulium* in Eastern Canada

1. Radius setose on its entire length 2
   Radius bare between the stem vein and radial sector; sector simple; calcipala and pedisulcus present and distinct; length of hind second tarsus less than twice the width of basitarsus; front usually broad; hairs on costa mixed with spinules . . . . . *Simulium* Latreille (p. 131)
2. Radial sector with a long fork; setae on costa not mixed with spinules; calcipala and pedisculcus absent; hind second tarsus much longer than width of basitarsus; front usually broad . . . . . *Prosimulium* Roubaud (p. 103)
   Radial sector simple (slightly forked in *lascivum*); setae on costa mixed with spinules; calcipala and pedisulcus present or absent; length of hind second tarsus less than twice the width of basitarsus; front narrowed . . . . *Eusimulium* Roubaud (p. 113)

Key to the Pupae of *Simulium* in Eastern Canada*

1. Cocoon of indefinite form; shapeless, loosely woven 2
   Cocoon of definite form; more or less closely woven 6
2. Pupal respiratory filaments 9; nearly as long as pupa . . . . . *decemarticulatum* n. sp.
   Filaments 12–16, distinctly shorter than pupa 3
3. Filaments 12 (sometimes 13 or 14), arising from two branches, about three-quarters as long as pupa . . . . . *mutatum* (Mall.)
   Filaments 14, arising from three branches 4
   Filaments 16, about one-half length of pupa . . . . . *hirtipes* Fries
   Filaments more numerous 5
4. Dorsal branch dividing into two stalks, each stalk bearing three filaments; filaments two-thirds length of pupa . . . . . *gibsoni* n. sp.
   Dorsal branch dividing into three stalks, each stalk bearing a pair of filaments; filaments two-fifths length of pupa, arctic species . . . . . *browni* n. sp.
5. Filaments 23–28; average 26 . . . . . *multidentatum* n. sp.
   Filaments 27–40; average 30 . . . . . *lascivum* n. sp.
6. Pupal respiratory filaments 4, in two pairs 7
   Respiratory filaments 6 10
   Respiratory filaments more numerous 12
7. Cocoon with long anterior process 8
   Cocoon without such process 9
8. Both pairs of filaments distinctly stalked . . . . . *latipes* Meigen
   One pair stalked, the other sessile, or nearly so . . . . . *rivuli* n. sp.
9. Both pairs of filaments on short stalks, the lower pair longer than the upper . . . . . *quebecense* n. sp.
   Lower pair sessile, upper pair shortly stalked . . . . . *aureum* Fries.
10. Cocoon with long anterior process; filaments nearly as long as pupa, in three stalked pairs, the upper pair divergent from the lower pairs . . . . *subexcisum* Edwards
    Cocoon without anterior process 11
11. Respiratory filaments slender, normal, about one-half as long as pupa; cocoon of wall-pocket type, entire . . . . . *venustum* Say
    perissum D. & S.
    Filaments stout, inflated, about one-fourth as long as pupa; cocoon slipper-shaped, with an anterior aperture on each side . . . . . *fibrinflatum* n. sp.
12. Respiratory filaments 8, six paired, two unpaired; about one-half as long as pupa; cocoon wall-pocket shaped . . . . . *ottawaense* n. sp.
    Respiratory filaments 9; about two-fifths as long as pupa; cocoon boot-shaped . . . . . *pictipes* Hagen
    Respiratory filaments 10; cocoon slipper-shaped 13
    Respiratory filaments 16; about three-quarters as long as pupa; cocoon wall-pocket shaped . . . . . *vittatum* Zett.
    Respiratory filaments approximately 200; short, hairlike, mainly simple, arising from five stout, rootlike tubes spread fingerwise; cocoon boot-shaped . *boreale* (Malloch)
13. Filaments dividing from two short branches, eight paired, two unpaired; about one-fourth as long as pupa, which averages 2.5 mm.; cocoon with anterior aperture on each side . . . . . *nigroparvum* n. sp.
    Filaments arising in sessile pairs from a common base; about three-eighths as long as pupa which averages 3.5 mm.; cocoon with anterior apertures and an interlacing basket-like extension . . . . . *corbis* n. sp.

* *Pupa of baffinense unknown; johannseni not included, owing to lack of material: it is apparently similar to aureum, with four filaments in each respiratory tuft.*

Subgenus *Prosimulium* Roubaud

Prosimulium Roubaud, Comp. Rend. Acad. Sci. Paris, 143 : 519, 1906.
Helodon Enderlein, Deuts. Tier, Woch., 29 : 199, 1921.
Taeniopterna Enderlein, Zool. Ans., 62 : 203, 1925.
GENOTYPE.—*Simulium hirtipes* FRIES.

KEY TO THE FEMALES OF *Prosimulium*

(Based on external characters and genitalia)

1. Claws bifid (*i.e.*, with basal tooth); antennae nine or ten-jointed 2
   Claws simple; antennae eleven-jointed 3
2. Antennae nine-jointed; tergal plates strongly chitinized, 3, 4, and 5 reduced in width; sternites 2, 3, 4, and 5 membranous; anal lobe sub-quadrate; apical expansions of genital rod transversely wrinkled; upper margins toothed . . . . *gibsoni* n. sp.
   Antennae ten-jointed; tergal plates weakly chitinized, 3, 4, 5, 6, and 7 greatly reduced in width; all sternites membranous; anal lobe broadly L-shaped; apical expansions of genital rod smooth, upper margins thickened . . . . *decemarticulatum* n. sp.
3. Tergal plates on segments 3, 4, and 5 greatly reduced; sternites 2, 3, 4, 5, and 6 membranous; anal lobe somewhat L-shaped 4
   Tergal plates not greatly reduced; sternites with small chitinized plates; anal lobe triangular; apical expansions of genital rod lanceolate, incurved, inner margins broadly chitinized . . . . . *browni* n. sp.
4. Ovipositor reaching tip of abdomen; apical expansions of genital rod quadrate; a large species . . . . . *multidentatum* n. sp.
   Ovipositor shorter and weaker; apical expansions of genital rod more or less triangular; medium sized species . . . . . *hirtipes* Fries.

KEY TO THE MALES OF *Prosimulium**

(Based on genitalia)

1. Claspers with a single terminal tooth; adminiculum arms broad medially 2
   Claspers with two or more terminal teeth; adminiculum arms narrow, strap-shaped . 3
2. Setae on side-pieces only on apical margin; claspers of even width throughout; prongs of adminiculum long, blunt; median process pointed at apex . . . . *gibsoni* n. sp.
   Setae on side-pieces more generally distributed; claspers sharply tapered; prongs of adminiculum short, pointed; median process broad and flat at apex . . . . . *decemarticulatum* n. sp.
3. One clasper with two, the other with three terminal teeth . . . . . *hirtipes* Fries.
   One clasper with four, the other with five terminal teeth . . . . *multidentatum* n. sp.

Simulium (Prosimulium) hirtipes FRIES.

Simulia hirtipes Fries, Mono. Simul. Suec., 1824 : 17.

Female.—Length†, 2–3 mm.; wing, 2.8–3 mm. Integument dark-brown to black; pile pale yellow. *Head:* front moderately broad, distinctly narrowed below; front and clypeus covered with pale yellow pilosity. Antenna 11-jointed, black, two basal joints paler. *Thorax:* mesonotum rather densely covered with pale yellow pile; pleural tuft pale yellow; scutellum with rather long, upright, yellow hairs. *Wings:* brownish; stem vein with pale yellow pilosity, other hairs dark brown; radial sector with a long fork; small basal cell present. *Legs:* brown, the coxae and tarsi darker; pubescence largely pale yellow; fore tarsi cylindrical, fore basitarsus a little shorter than the antenna; calcipala and pedisulcus absent; claws simple. *Abdomen:* basal fringe and short scattered pilosity on all segments, pale yellow; tergites three,

* *Male of browni n. sp. unknown.*
† *The linear measurements of the complete insect of this and all other included species were made from dried pinned specimens.*

four and five distinctly reduced; sternites two to six entirely membranous. *Genitalia* (Fig. 1, A, 5–6): ovipositor well developed, largely membranous, spiculate; inner margins thickly chitinized except the apical third: anal lobe broadly L-shaped, the basal portion equal in length to width of cercus and extending beneath it to the posterior margin; cercus rectangular, a little more than twice as wide as long; both evenly setulose and moderately setose; forks of the genital rod more or less triangularly expanded apically.

Male.—Similar in size, but darker than the female; pubescence on mesonotum coarse, yellow, rather dense, longer on posterior part and scutellum; pilosity on abdomen and legs longer and darker, particularly on the basal scale, venter and hind legs; legs uniformly darker; hind basitarsus more dilated, about equal in width to the tibia; claws bifid; abdominal tergites not greatly reduced; sternites not entirely membranous. *Genitalia* (Fig. 1, A, 1–4): side-piece slightly longer than broad, tapering; claspers shorter than

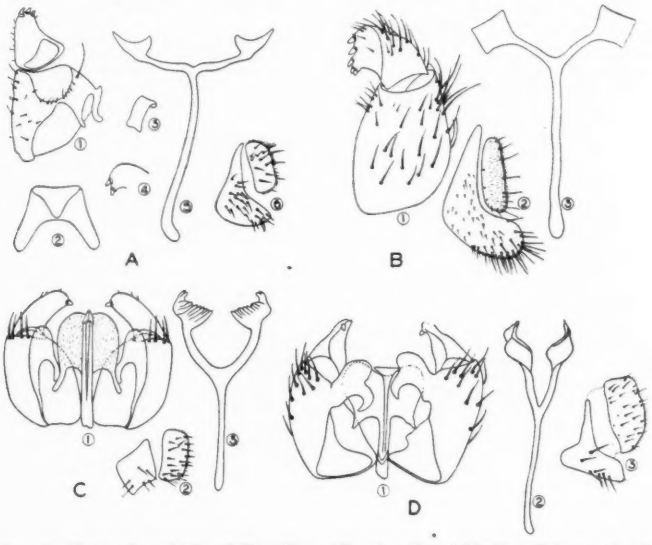


FIG. 1. *A. Parts of genitalia of Simulium (Prosimulium) hirtipes Fries: male (1) side-piece and clasper, (2) adminiculum, (3) adminiculum arm, (4) tip of opposite clasper; female (5) genital rod, (6) anal lobe and cercus. B. Simulium (Prosimulium) multidentatum n. sp.: male (1) side-piece and clasper; female (2) anal lobe and cercus, (3) genital rod. C. Simulium (Prosimulium) gibsoni n. sp.: male (1) side-pieces and claspers, adminiculum and adminiculum arms, median process or penis; female (2) anal lobe and cercus, (3) genital rod. D. Simulium (Prosimulium) decemarticulatum n. sp.: male (1) side-pieces and claspers, adminiculum and adminiculum arms, median process or penis; female (2) genital rod, (3) anal lobe and cercus.*

side-piece, conical; one clasper bears two short, stout, terminal teeth, and the other, three (Edwards, 6, p. 42, mentions this character as an abnormality in a British specimen he described, but evidently it is normal for the species); adminiculum broad, membranous, minutely pubescent medially; adminiculum arms smooth, strap-shaped, without teeth.

Pupa.—Length about 5 mm.; the respiratory tuft one-half as long as the pupa, consisting of 16 filaments. This character is constant for all the numerous pupae taken from streams in the Gatineau hills, Que., north of Ottawa, from which adult flies were reared. Various authors: Johannsen (23 and 24), Malloch (29), and others have indicated up to 60 or more respiratory filaments for this species in the United States. Puri (41, p. 362) states that pupae from France attain a total number of 50–60 filaments. He found, however, that pupae from Norway have only 16, and that as the species was originally described from Scandinavia the specimens must be regarded as typical. Puri's description of the filaments of the Norwegian specimens is in perfect agreement with my material and I cannot do better than quote from him: "The first division is near the base into three short stems, each of the two ventral stems dividing almost immediately into two branches, each of which bifurcates again. The upper stem again divides into three branches, the two lower ones dividing into three each and the upper into two. All the filaments are more or less of equal thickness and length." The cocoon consists of a mat of silk of indefinite shape which sometimes only partially covers the pupa, and to which extraneous matter, such as sand and tiny pebbles and fragments of stone is often attached.

Distribution.—Widespread in Europe and North America. Malloch (29, p. 29) and Dyar and Shannon (5, p. 9) give records from several of the states of the Eastern United States, and Labrador and Newfoundland. Dyar and Shannon state that the species appears to be confined to the region east of the Mississippi river and north of the Carolinas, but Malloch also includes records from Arizona, Idaho and British Columbia. Hearle (20, p. 8) records it from Banff, Alberta. It is possible that the western records concern allied species.

Simulium hirtipes occurs widely in Eastern Canada. I have examined specimens from the following localities. *Nova Scotia:* Kentville, 24. V. and 13. VI. 23 (R. P. Gorham); *New Brunswick:* Fredericton, 21. VI. 13 (collector unknown), Barber Dam, 23. VI. 14 (J. D. Tothill); *Quebec:* Grand Cascapedia, Gaspé, 16. IX. 32 (M. L. Prebble), Federal Mine, Cascapedia (2000′) 4. X. 32 (R. E. Balch), Gaspé, 26. VII. 33 (E. B. Watson), Hemmingford, 31. V. 26 and 25. VII. 28 (G. H. Hammond), St. Hilaire, 24. V. 06 (Beaulieu), Miners Bay, 26. V. 27 (F. P. Ide), Montebello, 21–31. V. 30 (N. J. Atkinson), Kingsmere, 14. V. 22 (J. McDunnough), Meach Lake, 24. V. 32 (C. R. Twinn), Hull, 22. V. and 10. VI. 23 (C. H. Curran), Chelsea, 5. VI. 19 (Arthur Gibson); *Ontario:* Ottawa, 13. V. 22 (J. McDunnough), Algonquin Park, 17. V. 32 (C. R. Twinn). I have also collected the immature stages and reared and collected adults in the Gatineau hills, Que., north of Ottawa, on several occasions in recent years.

Notes.—In the Ottawa district, the larvae and pupae of *S. hirtipes* have been found only in cold streams flowing down wooded hillsides from small

lakes, in the Gatineau hills (Laurentians), Que. In one of these streams (Fig. 2, A), pupae were found on May 2, 1935, when the temperature of the water was 47° F.; adults emerged indoors on May 4. Even in July, I found the temperature of this stream to be only 62° F. (July 22), but on that date *hirtipes* was replaced by *venustum*. Smart (49, p. 24) who gives the type locality as Lapland, states that *hirtipes* is typically a northern species, and an inhabitant of hill streams at Fortingal, in Scotland. In Eastern Canada, the adults are numerous in hilly, forested country in early spring, and may become abundant again in the autumn. I have found the pupae only in spring, and the species appears to have but one generation; overwintering in the larval stage. The females attack animals and man. Specimens of troublesome blackflies sent in by field officers of the Dominion Entomological Branch, from points in the forested region of New Brunswick and the Gaspé peninsula, have been this species and *S. venustum*.

Simulium (Prosimulium) multidentatum N. SP.

Female.—Length 2.7–3.5 mm.; wing 3.5–3.9 mm. closely allied to *hirtipes* Fries, but of more robust appearance; legs darker; general pilosity paler and more conspicuous; fore basitarsus slightly shorter than antenna (differs from *magnum* D. & S.). *Genitalia* (Fig. 1, B, 2–3): similar to, but larger and stronger than *hirtipes;* ovipositor chitinized, strigate, reaching tips of anal lobes which in turn extend beyond the cercus, and are strongly setose along the postero-ventral margin; cercus much wider than long, with elongate setae on the posterior margin; arms of genital rod quadrately expanded.

Male.—Essentially as in *hirtipes*, but more robust, and easily separated from it, and from *magnum*, by the number of teeth at the tip of the claspers. *Genitalia* (Fig. 1, B, 1): one clasper bears five short, stout, terminal teeth, the other four (the number being constant in several specimens examined); in other respects the genitalia are similar to *hirtipes*.

Holotype.—Male, near Hull, Que., reared from pupa, 3. V. 35. Can. Nat. Coll. (slide).

Allotype.—Female, same data.

Paratypes.—Eleven males, 13 females, 1–3. V. 35.

Pupa.—Length 5–6 mm. Respiratory tuft about one-third as long as pupa, comprised of 23–28 filaments (counts of six specimens gave 23, 25, 25, 26, 27, 28; an average of 26) branching from the main trunk, close to the base. The cocoon is indefinite in shape and dirty-gray in color. The pupae occur in close masses on submerged obstacles such as rocks, stones, pieces of wood and other debris.

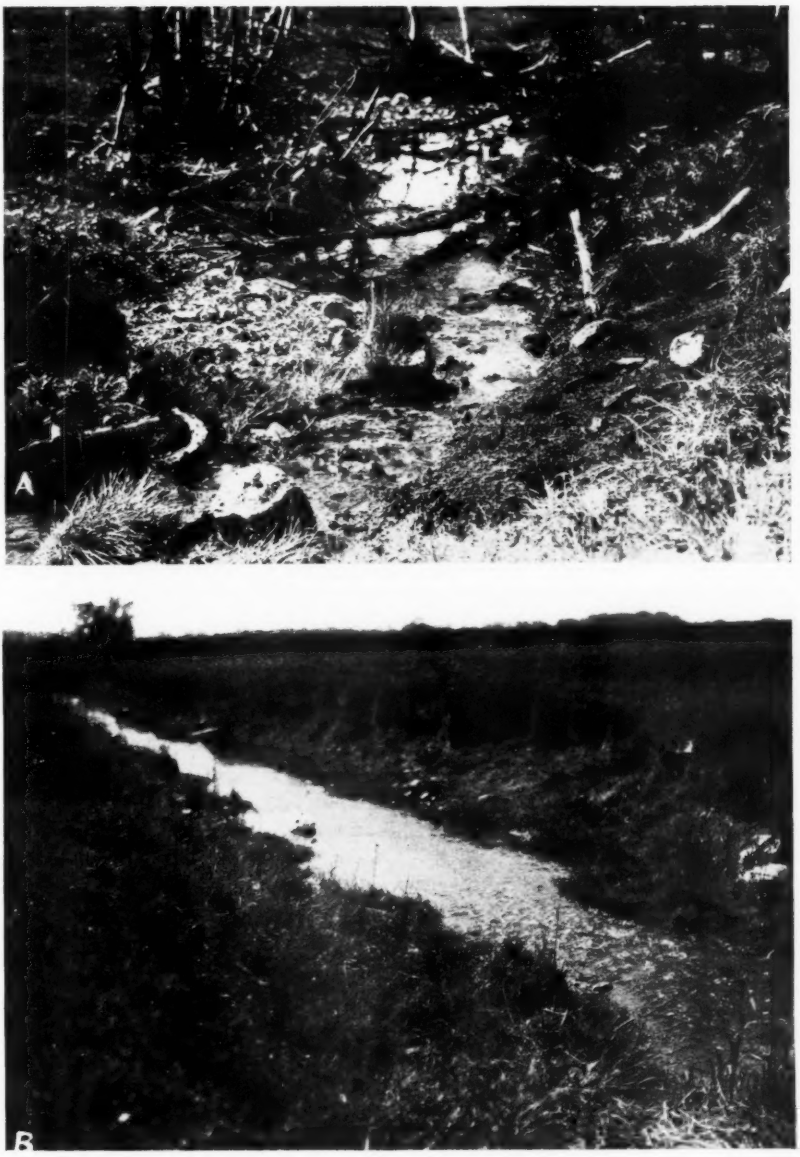


FIG. 2. *A. Stream (M.R. 1) in Gatineau hills near Hull, Que., habitat of S. hirtipes Fries and S. venustum Say. B. McEwan Creek, near Ottawa, Ontario, breeding place of S. vittatum Zett., S. venustum Say, and S. aureum Fries.*

Notes: Gross infestations of larvae and pupae of *multidentatum* were found on April 29, 1935, in two small, shallow, more or less parallel streams (Fig. 3, A and B), a few miles in length, which have their source south of the Gatineau hills and flow through agricultural land, finally emptying in the Ottawa river, near Hull, Que. The temperature of the water was 52° F. in one, and 54° F. in the other. No empty pupal skins were seen, but large numbers of adults of both sexes emerged between May 1 and 3 from pupae placed in moist vials at room temperatures.

A goodly proportion of the larvae were parasitized by nematodes. Infested individuals had distended abdomens and undeveloped histoblasts. The nematodes were coiled up in the abdomen; some of them measured more than an inch in length (one was 39 mm.), or three to four times as long as their hosts. An examination of 276 larvae showed 63, or 22.8%, parasitized. The nematodes left the larvae shortly after the latter were removed from the water. This may be the same species of parasite that Strickland (51, 52) recorded, in 1911, from larvae of *S. hirtipes* taken in streams near Boston, Mass. He concluded (51, p. 326) that the parasite, *Mermis* sp., "does not affect the larval development to any extent, except by slightly increasing its size, but it inhibits the development of the histoblasts to such an extent that pupation becomes impossible."

Emergence of the adults in the field had commenced on May 8, and was practically complete by May 14. No signs of the larvae were found throughout the summer, but their place was taken by sparse numbers of *vittatum*, *venustum* and *aureum*. Pupae and larvae which I collected on May 17, 1932, from Cranberry creek, Algonquin Park, Ontario, proved to be *multidentatum*.

Simulium (Prosimulium) gibsoni N. SP.

Female.—Length 1.6–1.9 mm.; wing 2.2–2.4 mm. Integument dark-brown to black; vestiture pale yellow. *Head:* front moderately broad, divergent-sided; front and clypeus with scattered pale hairs. Antenna dark reddish-brown; 9-jointed; a little shorter than the fore basitarsus; joints subequal, gradually tapering to the apex; joints eight and nine distinct, but incompletely separated; palpi black. *Thorax:* pile pale yellowish, the long hair on and in front of the scutellum also pale. *Wings:* with the characters of the subgenus; stem vein pale pilose; a few pale hairs mixed with the dark hairs elsewhere on the veins; halteres brown. *Legs:* dark-brown, distal segments of tarsi almost black; hairs pale-yellowish, especially long and conspicuous on the fore femora and hind legs; claws with a pointed basal tooth. *Abdomen:* basal fringe and short, rather sparse general pilosity, pale yellow; plates on the dorsum strongly chitinized, those on segments three, four and five reduced in width; sternites two to five largly membranous. *Genitalia* (Fig. 1, C, 2–3): anal lobe with few setae, small, more or less quadrate, slightly produced antero-dorsally; cerci rectangular, outwardly rounded, about twice as wide as long, moderately setose; arms of genital rod with apical membranous expansions transversely ridged or fluted, the upper margin crenulate.

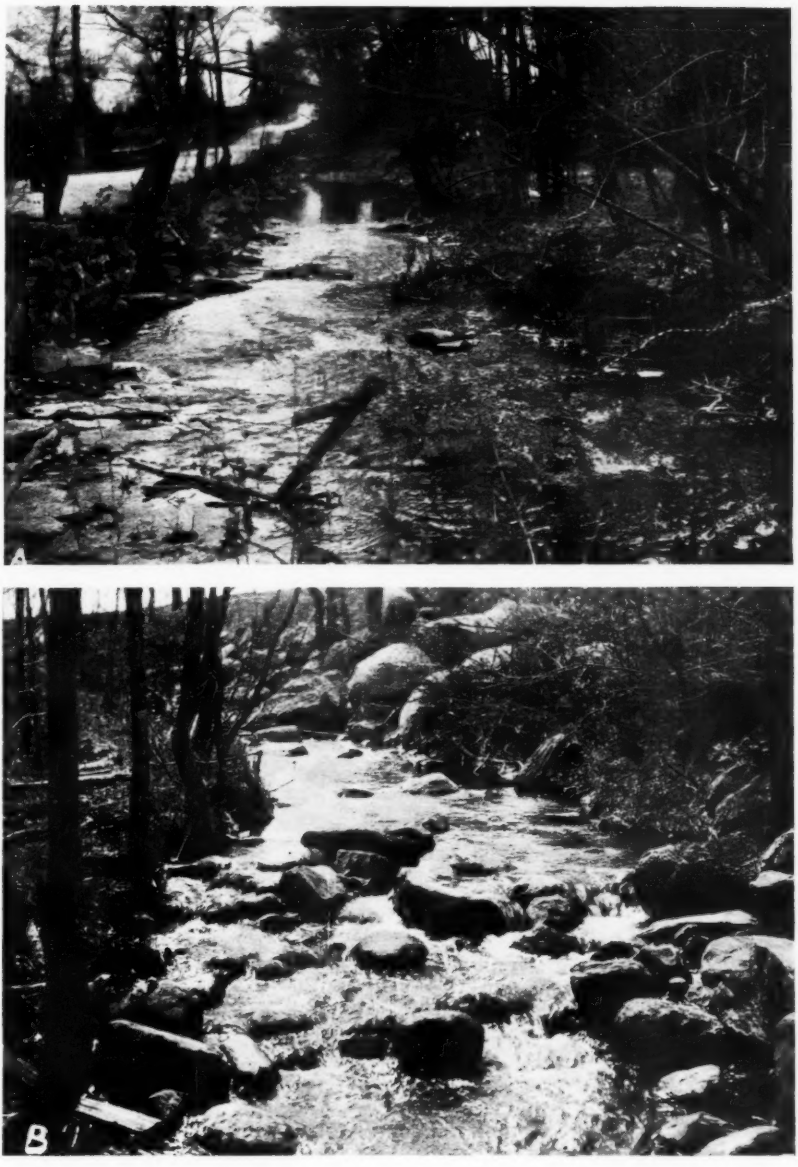


FIG. 3. *A. Simmons creek, near Hull, Que., breeding place of S. multidentatum n. sp., S. vittatum Zett., and S. venustum Say. B. Fairy Lake stream, near Hull, Que., breeding place of the above species and S. aureum Fries.*

Male.—Similar to female in size and color; pilosity somewhat longer; antennal joints eight and nine less distinctly separated; hind basitarsus equal in width to the tibia; tergal plates of abdomen not reduced; sternal plates weakly chitinized. *Genitalia* (Fig. 1, C, 1): side-pieces longer than broad, gently tapering, smooth, with a row of setae on the apical margin. Claspers a little longer than the side-pieces, with few setae and a short, stout, apical tooth. Adminiculum somewhat membranous, about as broad as long, setulose throughout, basal prongs chitinized, slender, divergent; adminiculum arms without teeth, broad medially and narrowed at both ends. Median process (penis ?) pointed at tip.

Holotype.—Female, near Carleton Place, Ont., emerged from pupa, 10. V. 35. Can. Nat. Coll.

Allotype.—Male, same data, 9. V. 35.

Paratypes.—Five females, 2 males, near Hull, Que., reared from pupae, 21–23. V. 35.

This species is dedicated to Dr. Arthur Gibson, Dominion Entomologist, whose kind approval made the present study possible.

Pupa.—Length about 3.8 mm. Respiratory tuft about two-thirds the length of pupa and comprised of 14 filaments, which divide from three branches, one dorsal and two ventral, arising from the main trunk. The dorsal branch divides into two, each part bearing three filaments, a single one and a short-stalked pair, thus forming six filaments; the ventral branches each bifurcate twice making eight filaments; or 14 in all. The cocoon, in which the pupa lies partially or wholly concealed, has no definite shape, and consists of loosely woven silk encrusted with tiny particles of sand. Sometimes the pupa is nearly naked.

Notes.—Larvae and pupae were collected during May, 1935, with other species, from three small, shallow, temporary streams draining pasture land near Hull, Que., and Carleton Place, Ont. A male emerged on May 9, and a female on May 10, from pupae taken on May 8, from the two streams near Carleton Place (C.P.H. 1 & 2: Fig. 4, A and B). Two males and five females emerged May 21-23, from pupae taken on May 19, on stones and pebbles in the stream (S. R. S. 1) near Hull, Que. Specimens were not seen during subsequent examinations, and the streams were dry in August. Numbers of empty pupal skins of *gibsoni* were found in the Blanche river, south of Perkins Mills, Que., on May 22. This is an early spring species with probably only one generation annually.

Simulium (Prosimulium) decemarticulatum N. SP.

Female.—Length about 2 mm.; wing 3 mm. A species with dark-brown integument, yellowish pilosity and yellowish-brown legs. *Head:* front moderately broad, distinctly narrowed below; surface hairs on front and clypeus

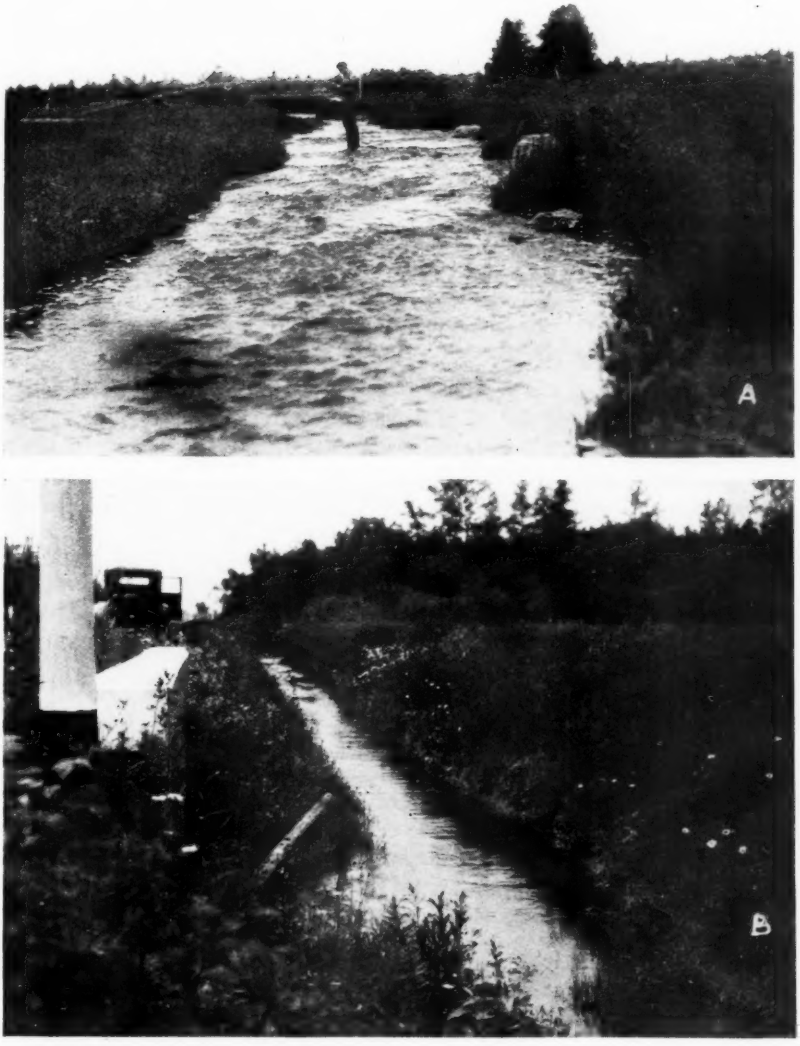


FIG. 4. *A. Stream (C.P.H. 2) near Carleton Place, Ont., habitat of S. gibsoni n. sp., S. decemarticulatum n. sp., S. mutatum Mall., S. subexcisum Edw., S. venustum Say, B. Roadside ditch (C.P.H. 1) near Carleton Place, Ont., breeding place of the above species and S. rivuli n. sp.*

largely pale, yellowish, postocular hairs black. Antenna 10-jointed; about one-third longer than the fore basitarsus; brown, basal joints paler; joints sub-equal, gradually tapering. *Thorax:* mesonotum rather densely covered with yellowish pubescence; the longer, upright hairs on and in front of scutellum, yellow; pleural tuft yellow. *Wings:* hairs on the stem vein pale yellow; elsewhere on the veins, dark; radial sector with a long fork; small basal cell present; halteres pale-brown. *Legs:* yellowish-brown, apical tarsal segments darker; pilosity yellow; calcipala and pedisulcus absent; claws bifid. *Abdomen:* basal fringe yellow; pilosity on the dorsum pale, sparse, denser at the sides; tergites weakly chitinized, the plates on segments three to seven greatly reduced in width; sternites entirely membranous. *Genitalia* (Fig. 1, D, 2–3): ovipositor valves weakly chitinized, extending slightly beyond base of anal lobe; cercus evenly and moderately setose, rectangular, twice as wide as long, the postero-ventral angle cut off by the inwardly directed posterior margin; anal lobe L-shaped, the broad basal portion nearly twice the length of the cercus, sparsely setose; upper arm narrow, thinly chitinized, bare; arms of genital rod narrowly divergent, expanded portions with upper margins thickened.

Male.—Similar in size to the female, but distinctly darker; integument dark-brown to black; mesonotal pile golden; pleural tuft black; hairs on scutellum dark; legs dark-brown, pilosity brown to black, in some places intermixed with paler, golden hairs, especially on femora; hind basitarsus dilated to about the width of tibia. *Genitalia* (Fig. 1, D, 1): similar to *gibsoni*, but side-pieces more setose; claspers sharply tapering; adminiculum broader than long, chitinized basal prongs very short and tapered; median process broad and flattened at apex.

Holotype.—Female, near Carleton Place, Ont., emerged from pupa 10. V. 35. Can. Nat. Coll.

Allotype.—Male, same data, 8. V. 35.

Paratypes.—Two females, same data, 9. V. and 13. V. 35.

Pupa.—Length about 4 mm. The respiratory tuft consists of nine long filaments, the longest nearly equalling the length of the pupa, arranged in a whorl, and bent almost at right-angles to the short base. The cocoon is of the usual *Prosimulium* type; shapeless and loosely woven. Those collected were encrusted with sand particles, which made the insect difficult to find.

Notes.—Larvae and pupae were found with immature stages of other species, in two shallow, temporary streams (Fig. 4, A and B) near Carleton Place, Ont., on May 8. One of the streams was a pebbly-bottomed, roadside drainage ditch, and the other flowed over a rock bottom through pasture fields. This is evidently an early spring species; no specimens were found two weeks later, and the stream dried up during the summer.

Simulium (Prosimulium) browni N. SP.

Female.—Length 2.5–3 mm.; wing 3.3–4 mm.; integument black, pilosity pale, yellowish. *Head:* front and clypeus black, rather sparsely clothed with black and pale hairs intermixed; front very broad, moderately narrowed below. Antenna 11-jointed, entirely black, distinctly longer than head and about one-third longer than the fore basitarsus; three basal segments enlarged, remainder smaller, tapering. *Thorax:* dull-black, concolorous; mesonotum with pale, sparse, recumbent pile; pleural tuft yellowish-brown, inconspicuous; marginal fringe of scutellum yellowish-brown, moderate. *Wings:* with a brown tinge; anterior veins brown; stem vein pale pilose; radial sector with a long fork; minute basal cell present; halteres dark-brown. *Legs:* dark-brown to black; pilosity pale yellowish, moderate; calcipala and pedisulcus absent; claws simple. *Abdomen:* black, basal fringe dark-brown; short, sparse, pale hairs on the tergites, longer and denser at the sides; tergites not markedly reduced; sternites all with small chitinized plates. *Genitalia* (Fig. 5): ovipositor valves similar to *hirtipes*, but infuscated, the setae longer, more numerous, basal half of inner margin chitinized, incurved; anal lobe scarcely larger than cercus, with numerous long setae on the ventral half; cercus rectangular, twice as wide as long, rounded distally, setose; genital rod stout, strongly chitinized, the arms broadly expanded, incurved.

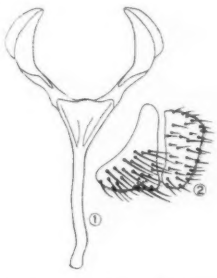


FIG. 5. *Parts of female genitalia of Simulium (Prosimulium) browni n. sp.: (1) genital rod, (2) anal lobe and cercus.*

Holotype.—Female, Lake Harbour, Baffin Island, 10. VIII. 35, reared from pupa (W. J. Brown). Can. Nat. Coll.

Paratypes.—Eleven females, same data.

Pupa.—Length 4.5 mm. Respiratory tuft about two-fifths as long as pupa, consisting typically of 14 filaments (one specimen had 15). The short main trunk gives rise to three branches, one dorsal and two ventral. The dorsal branch divides into three stalks, each of which bifurcates forming six filaments. The two ventral branches each give rise to four filaments, making 14 in all. The cocoon is of the usual type; a rather loosely woven sheath of indefinite shape. When undamaged it largely conceals the pupa.

Notes.—W. J. Brown, of the Dominion Entomological Branch, Ottawa, collected larvae and pupae from a stream at Lake Harbour, and reared the adults which comprise the type material. He also collected nine females on the wing, 5–10. VIII. 35. The species is dedicated to him.

Subgenus *Eusimulium* Roubaud

Eusimulium Roubaud, Comp. Rend. Acad. Sci. Paris, 143 : 519, 1906.

Cnephia Enderlein, Deuts. Tier. Woch., 29 : 199, 1921.

Cnetha Enderlein, ibid.

Nevermannia Enderlein, ibid.

Schonbaueria Enderlein, ibid.

Pseudonevermannia Baranoff, Neue Beitr. Syst. Ins., 3 : 164, 1926.

GENOTYPE.—*Simulium aureum* FRIES.

KEY TO THE FEMALES OF *Eusimulium**

(Based on external characters and genitalia)

1. Radial sector simple 2
   Radial sector weakly furcate 7
2. Claws simple 3
   Claws bifid (*i.e.*, with basal tooth) 4
3. Pedisulcus present, distinct; calcipala small; hind tibial spurs normal; thorax with three faint mesonotal vittae; hairs on stem vein largely yellow; anal lobe small, subquadrate, with a distal, rounded, setose protuberance; arms of genital rod quadrately expanded (arctic species) . . . . . *baffinense* n. sp.
   Pedisulcus absent; calcipala prominent; hind tibial spurs unusually long; mesonotum unstriped; hairs on stem vein black; anal lobe narrowed behind cercus, ventrally expanded, lobed beneath; arms of genital rod quadrately expanded, irregularly toothed . . . . . *mutatum* (Mall.)
4. Postnotum with patch of yellow scales; mesonotal pubescence brassy-yellow, scale-like; two basal joints of antennae pale-brown; anal lobe small, narrow, curved beneath cercus, ventral margin setose . . . . . *aureum* Fries
   Postnotum without scales; mesonotal pubescence pale; antennae entirely black . . 5
5. Mesopleural membrane with a tuft of pile; calcipala and pedisulcus absent; anal lobe normal, posteriorly setose . . . . . *boreale* (Mall.)
   Mesopleural membrane bare 6
6. Calcipala prominent; pedisulcus deep; hind basitarsus about 7.5 × 1; anal lobe normal; arms of genital rod irregularly expanded and terminating in a blunt chitinized tooth . . . . . *quebecense* n. sp.
   Calcipala small; pedisulcus shallow; hind basitarsus about 6 × 1; anal lobe subquadrate, the distal margin with a rounded, chitinized, setose process; arms of genital rod quadrately expanded . . . . . *subexcisum* Edw.
7. Calcipala minute; pedisulcus shallow; claws with small, sub-basal tooth; anal lobe elongate quadrangular, strongly setose; expansions of genital rod toothed and ribbed . . . . . *lascivum* n. sp.

KEY TO THE MALES OF *Eusimulium*†

(Based largely on genitalia)

1. Adminiculum narrow, conical; basal prongs widely divaricate . . . . . *aureum* Fries
   Adminiculum broad, rounded; basal prongs incurved, or only slightly divergent . . 2
2. Adminiculum with hirsute nipple in medial depression; adminiculum arms each with a single long, stout tooth . . . . . *quebecense* n. sp.
   Adminiculum without hirsute nipple; adminiculum arms with few to many, smaller teeth 3
3. Clasper with a pair of close-set terminal teeth . . . . . *mutatum* (Mall.)
   Clasper with a single terminal tooth 4
4. Radial sector weakly furcate; basal prongs of adminiculum roundly expanded . . . . . *lascivum* n. sp.
   Radial sector simple; basal prongs not rounded 5
5. Mesopleural membrane with a tuft of pile . . . . . *boreale* (Mall.)
   Mesopleural membrane bare 6
6. Pedisulcus deep; upper margin of adminiculum depressed; arms with numerous small teeth; large (arctic) species . . . . . *baffinense* n. sp.
   Pedisulcus shallow; upper margin of adminiculum convex; arms with few teeth; smaller species 7
7. Hind basitarsus about 6 × 1; adminiculum minutely hirsute, basal prongs incurved; arms with short stout teeth . . . . . *subexcisum* Edw.
   Hind basitarsus about 5 × 1; adminiculum with longer hairs, basal prongs not incurved; teeth on arms larger . . . . . *rivuli* n. sp.

* *Female of rivuli unknown; latipes and johannseni not included.*

† *Latipes and johannseni not included.*

Simulium (Eusimulium) aureum FRIES

Simulia aureus Fries, Monogr. Simul. Suec., p. 16, 1824.

Simulium bracteatum Coquillett, U.S.D.A. Bur. Ent. Bull. 10, n.s. p. 69, 1898.

Simulium angustipes Edwards, Bull. Ent. Res. 6 : 40, 1915.

Female.—Length, 2–3 mm.; wing, the same; integument black, grayish to brownish pollinose; pubescence silvery to brassy yellow. *Head:* front narrow, sides divergent; pilosity scale-like, creamy-yellow; clypeus distinctly longer than broad, pile finer and looser than on front; post-ocular hairs numerous, scale-like, pale yellow. Antenna 11-jointed, hardly tapering; black, the two basal joints pale-brown; palpi black. *Thorax:* mesonotum rather densely clothed with a yellow or brassy scale-like pile, somewhat silvery on the anterior margin; the recumbent pile and upright hairs on the scutellum, and a patch of scales on the postnotum, yellow; pleural tuft pale yellowish. *Wings:* hairs on the stem vein and base of costa pale-yellow; other hairs black, those on the costa mixed with minute spinules; the basal two-thirds of sub-costa with a sparse row of hairs. The radial vein hairy on its entire length, the hairs in a single row apically, interspersed with spinules. The radial sector simple; basal cell absent; halteres pale, the stem darker. *Legs:* pale-brown, except

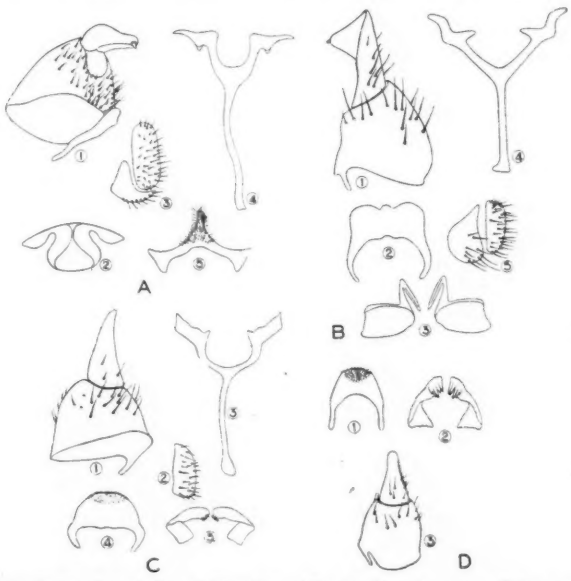


FIG. 6. *A. Parts of genitalia of Simulium (Eusimulium) aureum Fries: male (1) side-piece and clasper, (5) adminiculum, (2) adminiculum arms; female (3) anal lobe and cercus, (4) genital rod. B. Simulium (Eusimulium) quebecense n. sp.: male (1) side-piece and clasper, (2) adminiculum (hairs omitted from nipple), and (3) adminiculum arms; female (4) genital rod, (5) anal lobe and cercus. C. Simulium (Eusimulium) subexcisum Edwards: male (1) side-piece and clasper, (4) adminiculum, (5) adminiculum arms; female (2) cercus, (3) genital rod. D. Simulium (Eusimulium) rivuli n. sp.; male (1) adminiculum, (2) adminiculum arms, (3) side-piece and clasper.*

the mid and hind coxae, the apices of the femora and tibiae, and the tarsal joints, which are black. Pilosity on the pale parts silvery to yellowish; that on the dark parts black. Fore basitarsus a little shorter than antenna; hind basitarsus 6 × 1, about four-sevenths as wide as tibia; calcipala and pedisulcus distinct; claws distinctly bifid. *Abdomen:* basal fringe pale yellow; general pilosity rather dense, scale-like, yellow, sometimes silvery. The chitinized plates of tergites three to seven markedly reduced; sternites one to six membranous. *Genitalia* (Fig. 6, A, 3–4): ovipositor valves weakly chitinized, conical, pointed, reaching posterior margin of anal lobe; setose, spicular on distal two-thirds. Anal lobe smaller than cercus, curved, narrowed to a rounded point beneath cercus, but not reaching distal margin; setose on posterior margin only. Cercus slightly more than twice as wide as long, distally rounded, setose. Arms of genital rod broadly expanded, a blunt chitinized tooth on the outer margins.

Male.—Similar to the female except as follows: antenna more slender and entirely black; mesonotum densely clothed with golden pubescence, except the disc which is velvet black; halteres darker; legs as in female, but the pale parts a little darker, and the pilosity somewhat longer, particularly on the hind legs; the hind basitarsus about 5 × 1; narrower than the tibia; abdomen velvet black, the yellow pilosity less generally distributed, and rather longer and more hair-like; short and sparse on the apical segments; tergal plates not markedly reduced; chitinized sternal plates present on all but the second segment. *Genitalia* (Fig. 6, A, 1, 2, 5): side piece conic-quadrate; clasper small, angled, terminating with a short tooth. Adminiculum narrow, somewhat conical, hirsute, the basal prongs widely divaricate and outwardly triangularly expanded. Adminiculum arms connected medially with a convex membrane; lateral chitinous plates broad.

Pupa.—Length about 3 mm.; the respiratory filaments a little longer than the pupa, four in each tuft, all of about equal thickness, arising in two pairs; the lower pair directly from the main trunk, and the upper pair on a very short stalk. The cocoon is of rather tightly woven silk, of the typical wall-pocket form; about one-third longer than wide. The thickened anterior margin bulges to form a slight median salient.

Synonymy.—Dyar and Shannon (5, p. 14) placed *bracteatum* Coquillett as a race of the European *aureum* Fries. Edwards (7, p. 243) stated that he examined a male of *bracteatum* from Spartanburg, S.C., and could find no appreciable difference from the European *aureum* in the genitalia or other characters; furthermore, descriptions of the larvae and pupae by Strickland (50) and Jobbins-Pomeroy (38, p. 13) also agreed with the British form. After careful comparison of my material with Edwards' descriptions of the male and female of *aureum* (6, pp. 39–40), the former under the synonym *angustipes*, and with descriptions of the larvae and pupae by Edwards (7, p. 242) and Puri (41, p. 355), I am convinced that the North American form is identical with the European *aureum* and have placed *bracteatum* as a synonym of the former.

Notes.—I have collected the larvae and pupae in several localities in Ontario and Quebec, in the Ottawa region, always in small, shallow streams, and usually associated with *venustum* and *vittatum*, but never very numerous. The type of stream (Fig. 2, B and Fig. 3, A) favored, commonly has a stony, pebbly, or shaly bottom, and is usually temporary or semi-permanent in character. There are probably two, perhaps three, generations annually. Pupae were found in June, July, and September. Both sexes were reared from Pink's Lake stream, near Hull, Que., Sept. 25, 1934, and June 12, 1935, and from McKay Lake stream, Rockcliffe, Ont., June 28, and July 24, 1935. Apparently nothing is known of the habits of this species as a bloodsucker.

Distribution.—The records given by Dyar and Shannon (5, p. 14) and by Malloch (29, p. 38) under the name *bracteatum* show this species to occur widely in the eastern United States. It is also recorded from the west by the same authors (Alaska, California and Colorado). Edwards (8, p. 150) states that it occurs throughout Europe and North America. I have the following records for Canada; the collections were pupae unless otherwise indicated. *Ontario:* Bowesville, June 12, 1926; Billings Bridge, Sept. 23, 1926; Rockcliffe, Sept. 27, 1926; June 2, 1931 (reared adults, June 28 and July 24, 1935); Hawkesbury (larvae), July 25, 1927. *Quebec:* Gracefield, July 13, 1926; Luskville, July 22, 1931; Pink's Lake (near Hull), July 21, 1931 (reared adults Sept. 25, 1934 and June 12, 1935). The species is probably widespread in Eastern Canada.

Simulium (Eusimulium) quebecense N. SP.

Female.—Length about 1.6 mm.; wing 2.6 mm.; integument black with grayish pollinosity; vestiture pale. Closely related to *aureum* Fries, with identical characters except as follows: pubescence paler throughout, silvery to yellowish-white or gray, less scale-like; antenna entirely black; postnotum bare; hairs on stem vein pale; legs more slender and darker, the apical bands on the femora and tibiae indistinct, even in cleared specimens; pilosity on the legs pale, the hairs darker on the tarsal joints; hind basitarsus 7.5 × 1; abdominal pubescence pale and much sparser. *Genitalia* (Fig. 6 B, 4–5): ovipositor valves membranous, chitinized on the inner margins, tips not reaching ninth sternite. Anal lobe about twice as long as cercus, broadly rounded, apically produced, pyriform, with sparse long setae postero-ventrally; cercus a little more than twice as wide as long, setose. Genital rod widely forked, each arm irregularly expanded and terminating with a blunt chitinized tooth.

Male.—Slightly larger than female; integument and pubescence much darker; antennae and palpi more slender. Mesonotum velvet black, with pale-yellowish rather scale-like pilosity, the hairs most numerous anteriorly, sparse on the disc; recumbent scales on the scutellum pale, upright hairs black; pleural tuft black. Hairs on the stem vein black; halteres black. Legs dark-brown to black, the pile dark and rather long, especially posteriorly on the front femora and hind legs; hind basitarsus broad, about 3.5×1, six-sevenths the width of the tibia; basal tooth on claws somewhat smaller. Abdomen

velvet brown, almost black; other pubescence the same, but short and sparse on the dorsum, long on the sides and sternites. Tergal plates two to six slightly reduced; second sternite entirely membranous. *Genitalia* (Fig. 6, B, 1–3): side-piece conic-quadrate; clasper about as long as side-piece, apical portion conically produced at right-angles to the main axis, and with a small terminal tooth. Adminiculum broad, the centre of the upper margin depressed and bearing a rounded hirsute nipple; basal prongs long, chitinized, incurved. Adminiculum arms rounded-quadrate basally, each bearing a single long, stout, pointed tooth.

Holotype.—Female, near Perkins Mills, Que., 26. V. 35 (reared). Can. Nat. Coll.

Allotype.—Male; same data.

Paratypes.—Four females, five males; same data.

Pupa.—The pupa and cocoon closely resemble those of *aureum* Fries, but both pairs of filaments are arranged on short stalks arising from the main trunk, the lower stalk a little longer than the upper stalk: the uppermost filament slightly swollen at the base. The cocoon is more tightly woven, and the anterior margin thicker.

Notes.—Pupae from which the type material was reared were collected on May 22, 1935, from stones in the rapids of the Blanche River, a short distance below the falls, about five miles south of Perkins Mills, Que. (Fig. 7, A). The temperature of the water was 53° F. At this point the river is shallow and swift, over a stony bottom. A pupal skin of *hirtipes*, some mature larvae of *venustum*, and a number of pupae of *corbis*, were taken at the same time, the latter on submerged dogwood.

Simulium (Eusimulium) subexcisum Edwards

Simulium subexcisum Edwards, Bull. Ent. Res. 6 : 41, 1915.

Female.—A small, dark-colored species, integument brown to black; pubescence pale. *Head:* antenna entirely black, 11-jointed; second joint swollen, about equal in length to third joint, remainder smaller, sub-equal, gradually tapering to a point. *Wings:* hairs on apical half of costa mixed with spinules; an irregular row of hairs present on the basal two-thirds of the subcosta; radial vein clothed with fine hairs throughout its length, the apical ones in a single row interspersed with several spinules; radial sector simple; there is a slight but perceptible thickening of the vein, and a slight divergence of the two rows of hairs at the apical margin. *Legs:* all the joints in the cleared specimen uniformly dark; fore and mid basitarsi cylindrical; hind basitarsus flattened, about 6 × 1 and three-fifths width of tibia; calcipala small, narrow; pedisulcus shallow; claws with a prominent basal tooth. *Abdomen:* width of tergal plates three to seven much reduced; sternites largely membranous. *Genitalia* (Fig. 6, C, 2–3): anal lobe small, sub-quadrate, weakly chitinized; ventral margin curved, minutely nodulose, spiculate; distal

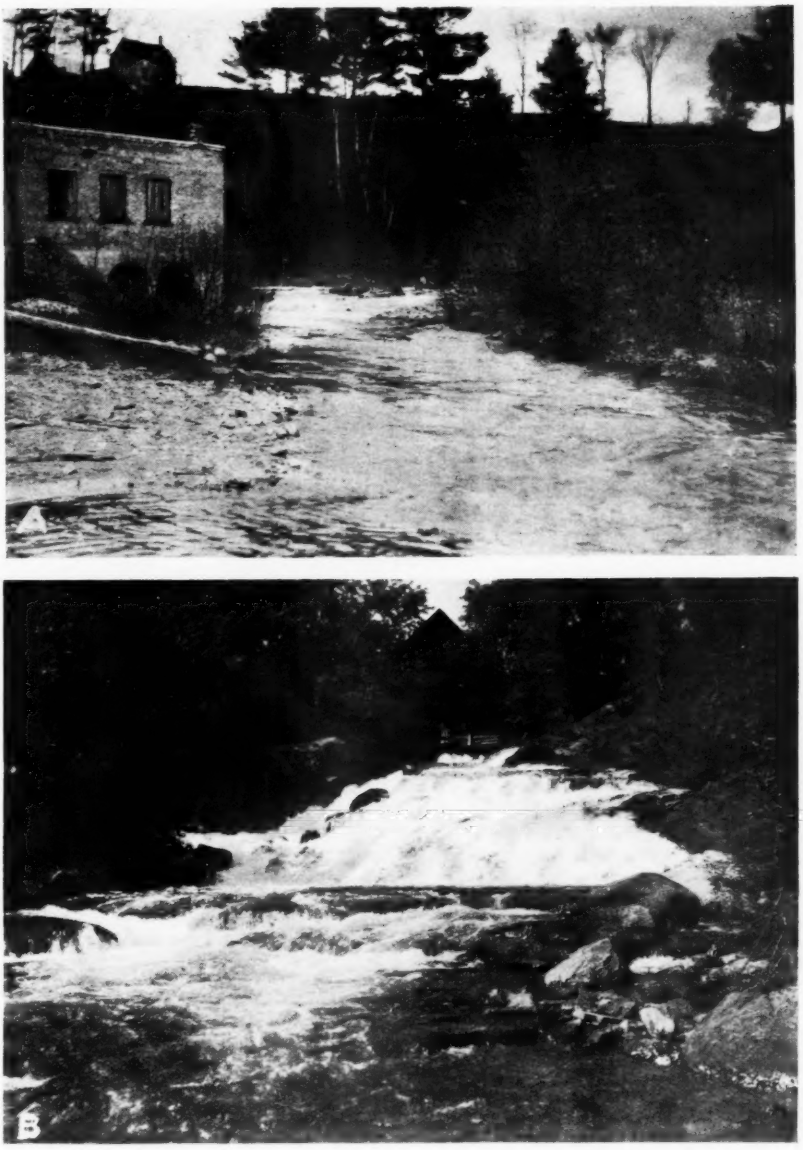


FIG. 7. *A. Blanche river, south of Perkins Mills, Que., S. gibsoni n. sp., S. venustum Say, S. quebecense n. sp., S. corbis n. sp. and S. nigroparvum n. sp., breed here. B. Falls of Blanche river at Perkins Mills, Que.; breeding place of S. pictipes Hgn.*

margin ventrad of cercus, with a rounded chitinized process bearing two or three long setae. Cercus wider than long, distally rounded, moderately setose. Arms of genital rod quadrately expanded outwardly, the expanded portion weakly chitinized and with the upper-inner margin drawn into a small pointed tooth-like process.

Male.—Differs from female as follows: maxillary palpi markedly shorter than antennae; row of hairs on sub-costa absent; legs in cleared specimen paler, apices of hind and mid femora and all tibiae distinctly darkened; hairs on front femora, hind femora and tibiae longer; abdominal tergites not greatly reduced; only second sternite entirely membranous. *Genitalia* (Fig. 6, C, 1, 4, 5): side-piece conic-quadrate, about as broad as long. Clasper as long as the side-piece, tapering, pointed, with a very small terminal tooth. Adminiculum broadly rounded, minutely hirsute, the basal prongs stout, chitinous, incurved. Adminiculum arms with a group of several short, rather stout teeth.

Pupa.—Length about 3 mm. Respiratory tuft almost as long as the pupa, consisting of six filaments arranged in pairs; the upper pair with a long stalk, widely divergent from the two lower pairs. The cocoon is about 4 mm., less closely woven than *latipes*, and with a thickened anterior margin and long anterior process.

Notes.—This species has not previously been recorded in North America. Edwards described both sexes from specimens collected in England, and has recorded it (6, p. 41 and 7, p. 244) from various localities in the British Isles, where it appears to be somewhat rare. Apparently little is known of its habits. Edwards states that, "there cannot normally be more than one brood in the year." Several pupae were found on May 8, on stones in a temporary rill (Fig. 4, B) near Carleton Place, Ont., with pupae of certain other species, Two males and one female emerged on May 13, and were placed on slides with genitalia dissected. I have not seen European specimens of the species, but have compared my material with the descriptions and illustrations of the adults published by Edwards (6, p. 41), and of the pupae by Edwards (7, p. 244) and Puri (41, p. 358).

Simulium (Eusimulium) rivuli N. SP.

Male.—Closely allied to *subexcisum* Edw., but may be separated from it by the following structural characters, and by the pupa. Palpi almost as long as antennae; hind basitarsus about 5 × 1, and four-fifths the width of tibia. *Genitalia* (Fig. 6, D): similar to *subexcisum*, but about one-fourth smaller; hairs on adminiculum longer, basal prongs not distinctly incurved; teeth on adminiculum arms larger.

Holotype.—Male, near Carleton Place, Ont., emerged from pupa 13. V. 35: Can. Nat. Coll. (slide).

Paratypes.—One male, dissected from pupa taken near Hull, Que., May 19, 1935 (slide).

Pupa.—Length 3.1 mm. Respiratory filaments about 3.6 mm., of equal thickness; four in number in two pairs: the first pair almost sessile; the second, distinctly stalked. The cocoon has a long anterior process, and is similar to the cocoon of *subexcisum* Edw.

Notes.—The male emerged on May 13, 1935, from a pupa taken, May 8, in a temporary rill, or drainage ditch, with a pebbly bottom (Fig. 4, B) several miles from Carleton Place, Ont. Unfortunately the specimen was cleared and mounted with its genitalia dissected before a note was made of its color and pubescence. Two other pupae were secured but died: one was collected with the type; the other came from S.R.S. 1, a temporary rill of similar character, near Hull, Que. In the latter, an adult male had almost completed its development, and I was able to dissect out the genitalia. The pupae were found in association with *subexcisum*, *latipes*, and several other species.

Simulium (Eusimulium) latipes MEIGEN

Simulium latipes Meigen, Klass. 1. 96. 5, 1804; Syst. Beschr. 1. 297. 11, 1818.

A pupa and cocoon that agree with the description of the European *latipes* published by Puri (41, p. 352), were collected on May 19, 1935, on a stone in a temporary rill (S.R.S. 1)* near Hull, Que., with larvae and pupae of several other species. The pupa is smaller than Puri's specimens, measuring 3.2 mm. The respiratory filaments are about 3.7 mm., four in number, arising from a short main trunk in two distinctly stalked pairs held in the vertical plane. The cocoon is closely woven, its anterior border strongly thickened and extending forward in a flat median process about 1.1 mm. long. It measures 3.6 mm., without the process, and is about one and one-quarter times as long as broad. The floor is restricted to the posterior half of the cocoon.

Simulium latipes has not previously been recorded in North America, but is widespread in Europe. Edwards (7, p. 239) states that its habitat, in the British Isles, is small temporary rills and streams, with stony bottoms, the flies emerging in spring. He recorded the females biting humans.

Simulium (Eusimulium) johannseni HART

Simulium johannseni Hart, 27th Rept. Sta. Ent. Ill. p. 32, 1912.

Dyar and Shannon (5, p. 23) record the taking of *johannseni* at Waubamic, Parry Sound, Ontario, by J. M. Aldrich, on June 8, 1915. There appear to be no other Canadian records. I have not found specimens of this species.

Simulium (Eusimulium) baffinense N. SP.

Female.—Length, 2.7 mm.; wing 3 mm. Integument black, grayish pollinose; pubescence yellow. *Head:* front rather narrow, sides moderately divergent; median furrow distinct; front and clypeus grayish pollinose,

** After careful search, I found two pupae of the same species in this stream in May, 1936; a female emerged from one on May 16, and a male from the other on June 1. The characters given in Edwards' (6 and 7) keys and description indicate them to be S. latipes Mgn.*

sparsely pale haired; postocular hairs largely yellow, some black. Antenna 11-jointed, entirely black, rather slender, tapering, basal joints slightly enlarged; maxillary palpi black, nearly as long as antenna. *Thorax:* mesonotum with fairly dense, sub-appressed, rather scale-like pilosity, golden on the disc, longer and paler along the margins; the integument of the mesonotum bears three faintly marked vittae, obscured by the hairs, the lateral ones diverging posteriorly; scutellum with numerous upright yellow, marginal hairs; postnotum bare, pollinose; pleural tuft yellowish. *Wings:* yellowish hyaline; anterior veins brown; posterior veins not darkened; hairs on stem vein yellow, or with a few black ones intermixed; hairs on costa intermixed with spinules, these most numerous and prominent apically; sub-costa with a weak row of hairs on basal half; radius rather sparsely haired throughout its length, those on apical half in a single row alternating with spinules; the radial sector simple and bearing a single row of fine hairs; basal cell present, minute, indistinct; halteres pale, the stem black. *Legs:* dark-brown to black, with yellowish pile; apices of femora, and bases and apices of tibiae with chitinized

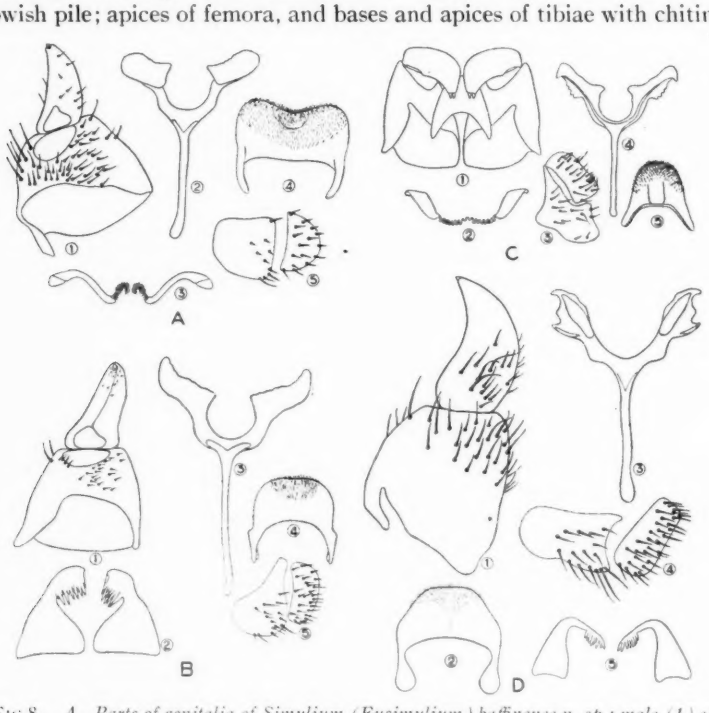


FIG. 8. *A. Parts of genitalia of Simulium (Eusimulium) baffinense n. sp.: male (1) side-piece and clasper, (4) adminiculum, (3) adminiculum arms; female (2) genital rod, (5) anal lobe and cercus. B. Simulium (Eusimulium) boreale (Malloch): male (1) side-piece and clasper, (4) adminiculum, (2) adminiculum arms; female (3) genital rod, (5) anal lobe and cercus. C. Simulium (Eusimulium) mutatum (Malloch): male (1) side-pieces and claspers, (5) adminiculum, (2) adminiculum arms; female (3) anal lobe and cercus, (4) genital rod. D. Simulium (Eusimulium) lascivum n. sp.: male (1) side-piece and clasper, (2) adminiculum, (5) adminiculum arms; female (3) genital rod, (4) anal lobe and cercus.*

black bands (very distinct in cleared specimens); basitarsus and second hind joint less heavily chitinized than front and mid tarsal joints; fore basitarsus cylindrical, about four-fifths as long as antenna; hind basitarsus about 6 × 1, and two-thirds width of tibia; calcipala small; pedisulcus present, near the base of the second hind tarsal joint, the incision deep and distinct; claws simple. *Abdomen:* basal fringe pale yellow; dorsum with somewhat sparse yellowish pubescence, hairs longer and more numerous at the sides; width of tergal plates three to seven moderately reduced; sternites two to six entirely membranous. *Genitalia* (Fig. 8, A, 2, 5): ovipositor rather short and broad; valves membranous, inner margins chitinized. Anal lobe small, chitinized, sub-quadrate, sparsely setose distally, membranous and spiculate ventrally, postero-ventral margin lobed; posterior margin above lobe with a heavily chitinized rounded protuberance ventrad and anterior to cercus, bearing several rather long setae (some of characters not well shown in figure). Arms of genital rod expanded outwardly into rounded quadrate, weakly chitinized plates.

Male.—Similar to female, but postocular hairs black; hairs on stem vein black; sub-costa bare; halteres black; legs entirely black; hind tibia and basitarsus somewhat enlarged, the basitarsus about 4 × 1, and four-fifths the width of tibia; claws with a rather strong basal tooth; abdominal tergites not greatly reduced; only the second sternite entirely membranous. *Genitalia* (Fig. 8, A, 1, 3, 4): side-piece large, conic-quadrate; clasper a little shorter, tapering, and terminating with a small tooth. Adminiculum twice as wide as long, weakly chitinized and clothed with longish hairs; upper margin depressed; basal prongs prominent, chitinous and slightly incurved. Adminiculum arms with numerous short teeth mixed with fimbriae; narrow laterally.

Holotype.—Female, Lake Harbour, Baffin Island, 10. VIII. 35 (W. J. Brown). Can. Nat. Coll.

Allotype.—Male, same data.

Paratypes.—Two females, nine males, with types. A pair of these were pinned in copula and have been cleared and mounted on the same slide.

I have also five females structurally indistinguishable from the types, but with distinctly paler pubescence; the mesonotal vittae more distinct; the hairs on radial sector arranged in an irregular double row.

In the event that these characters prove to be constant, the name *pallens* is proposed for this form.

Simulium (Eusimulium) boreale (MALLOCH)

Prosimulium borealis Malloch, Rept. Can. Arctic Exp., 1913–18, Vol. 3, p. 41 C, 1918.

Female.—Length about 2.5 mm.; wing 3.5 mm. Integument black, dusted with gray to brownish pollinosity. Differs from *baffinense* as follows: vestiture including the anterior veins of the wings, pale, silvery; pleural tuft longer, more conspicuous; a tuft of pale pile on the mesopleural membrane; meso-

notal vittae more distinct; hairs on stem vein silvery; the row of hairs on sub-costa confined to outer three-fourths of vein; hairs on radius more numerous; basal cell small, but distinct; legs entirely dark; chitinous black bands absent; fore basitarsus about six-sevenths the length of antenna; hind basitarsus about 7 × 1; calcipala and pedisulcus absent; claws with a rather strong, pointed, basal tooth; reduction of width of tergal plates slightly less marked. *Genitalia* (Fig. 8, B, 3, 5): ovipositor valves short, broad at base, membranous, except along inner margins, sparsely spicular, tips not reaching ninth sternite. Anal lobe weakly chitinized, more or less triangular, ventral margin rounded; setae rather numerous on postero-ventral two-thirds. Cercus sub-quadrangular, broader than long, slightly narrowed below, setose. Arms of genital rod expanded into more or less quadrangular plates, each with a transverse, strongly chitinized ridge which forms a large blunt tooth (not shown in figure).

Male.—Postocular hairs black; general pilosity pale as in female, the hairs on the mesonotum rather sparser and longer; vittae less distinct; hind basitarsus about 4 × 1, as wide as tibia; tergites and sternites not much reduced. *Genitalia* (Fig. 8, B, 1, 2, 4): side-piece and clasper similar in size and shape to *baffinense*, but with fewer setae; adminiculum about three-fourths as wide, and basal prongs slightly produced laterally. Adminiculum arms with long, conspicuous teeth medially, fimbrious above; lateral plates broadly expanded.

Notes.—Malloch's type material was collected on the Wollaston peninsula, Victoria Island, during the summer of 1915, by D. Jenness; a female specimen was taken at Bernard Harbour, Northwest Territories, August 25, 1916, by F. Johansen (30). I have examined the genitalia of Malloch's type specimen, which is in the Canadian National Collection, and find it to be a female, not a male, as erroneously stated by him. This mistake was doubtless due to the rather poor condition of the specimen, which superficially resembles a male owing to the collapsed condition of the eyes.

Dyar and Shannon (5, p. 22) record the collection of three females by Dr. Dyar at Two Medicine River, Montana, on July 27, 1921. My material consists of a male and seven females collected at Lake Harbour, Baffin Island, August 5–10, 1935, by W. J. Brown.

Hearle (20, p. 11) states that this species is one of the commonest in the Kamloops district, British Columbia, and that he reared large series of both sexes from a number of small streams, rather slow-flowing, over rocks. There are about a dozen specimens of both sexes in the National Collection reared by Mr. Hearle in June, 1930, and May, 1931. An examination of slide preparations of the genitalia of one of each sex shows them to be identical with the specimens from Baffin Island, and with the type. Hearle described the hitherto unknown pupa and cocoon as follows: "Each breathing organ has five stout rootlike tubes of varying sizes spread fingerwise and arising from a bulbous base, two tubes paired; from all five tubes are a very large number (approximately 200 in all) of short hairlike white filaments of about equal size and mainly simple. Case pale-grey, of smooth texture and boot-shaped".

Simulium (Eusimulium) mutatum (MALLOCH)

Prosimulium mutatum Malloch, U.S. Dept. Agr. Bur. Ent. Tech. Ser. No. 26, 1914, p. 20.

Undescribed species No. 2, Ritcher, Ent. News XLII : 241, 1931.

Female.—Length, 2–3 mm.; wing, 2.5–3.5 mm.; integument grayish or brownish to black, sub-opaque. *Head:* front narrow, sides moderately divergent, median groove distinct; clypeus longer than broad; front and clypeus sparsely pale haired; orbital hairs largely pale. Antenna 11-jointed; entirely black; joints sub-equal except the second, which is somewhat enlarged, and the apical joint, which tapers to a point; palpi black. *Thorax:* mesonotum moderately densely clothed with grayish-yellow, hair-like pilosity; scutellum with pale and dark hairs intermixed; postnotum bare, silvery pollinose, shining; pleural tuft pale. *Wings:* hairs on stem vein black; other hairs dark, those on the apical two-thirds of costa mixed with numerous spinules; hairs on lower surface of sub-costa in a double row at the base, singly outwardly; radial vein hairy throughout its length, the distal hairs in a single row. Radial sector simple; a small basal cell present and distinct; halteres pale-brown. *Legs:* yellowish-brown to dark-brown, more or less concolorous; pilosity largely pale-yellow. Fore and mid tarsi cylindrical; hind tibial spurs unusually long, length nearly four-fifths width of tibia; calcipala distinct; pedisulcus absent; claws simple. *Abdomen:* basal fringe pale; general pubescence pale, sparse, minute, and largely confined to apical segments. Width of chitinized plates of tergites three to six markedly reduced; tergites two and seven also reduced, but less so; sternites of all but the first and terminal segments membranous. *Genitalia* (Fig. 8, C, 3, 4): ovipositor valves small, inconspicuous. Anal lobe narrowed behind cercus, expanding ventrally to about twice the length of cercus; distal portion lobed, setose, and projecting beneath it; cercus about twice as wide as long, setose. Arms of genital rod broadly and quadrately expanded; lower margins irregularly toothed.

*Male**.—Similar in size, but distinctly darker than the female. Mesonotum dull velvet-black, with rather sparse, scattered, bronzy-brown to black scale-like pilosity; marginal fringe on scutellum black; pleural tuft longer than in female, black; halteres dark-brown. Legs uniformly darker and more hirsute, the hairs bronzy black, and longer, especially on the fore femora and hind legs. Hind tibia and basitarsus broader than in female, but in the same relation to each other, the basitarsus about five-sixths the width of tibia. Calcipala smaller; hind second tarsus with an indistinct pedisulcus. Claws trifid. Abdomen velvet black, the apical margins paler; basal fringe black; pubescence short, rather sparse, bronzy black. Tergal plates less markedly reduced than in female, the reduction progressively decreasing from segments two to seven; only the sternite of second segment entirely membranous. *Genitalia* (Fig. 8, C, 1, 2, 5): side-piece conic-quadrate, longer than broad,

* *Previously undescribed.*

setose distally. Clasper setose, shorter than side-piece, rather wide, uniform, but suddenly tapering near tip and bearing a pair of closely set, blunt, terminal teeth. Adminiculum broadly rounded, chitinized, hirsute; basal prongs strong, divergent. The adminiculum arms bear a marginal row of irregular, blunt teeth medially.

Allotype.—Male, near Carleton Place, Ont., reared from pupa, 9.V.35. Can. Nat. Coll.

Paratypes.—Three males, same data, 9–13. V. 35.

Pupa.—Length about 3–4 mm.; respiratory tuft about three-quarters the length of pupa. The main trunk divides close to the base into two branches held in the vertical plane. The upper branch further subdivides into seven filaments; the lower, into five, forming twelve in all. In some specimens the unpaired filament of the lower group divides into two near the apex, or one of the paired filaments gives rise to a short branch, or a weak filament arises from the main stem of the upper group. Thus the number of filaments varies from twelve to fourteen, but the usual number is thirteen. The cocoon is similar to that of *Simulium (Prosimulium) gibsoni;* indefinite in shape and consisting of loosely woven silk encrusted with coarse sand particles.

Synonomy.—Under the name *Undescribed Species No. 2*, Ritcher (44, p. 241) published a description of the immature stages of a species collected from a small temporary woodland stream near Urbana, Illinois, in April, 1930. Comparison of his descriptions and figures of the larva and pupa with my specimens show them to be identical.

Notes.—During May, 1935, I found small numbers of larvae and pupae in three small temporary streams flowing through rough pasture land in the Ottawa district, and succeeded in rearing four males and eight females. These males are the first to be recorded, and this is the first time that the immature stages have been associated with the adults. The species was found in association with *venustum*, *latipes*, *subexcisum*, *decemarticulatum* and *gibsoni*. The details of the collections are as follows. On May 8, larvae and pupae were found on stones in a shallow drainage ditch (C.P.H. 1), and in a rock-bottomed stream (C.P.H. 2), several miles from Carleton Place, Ont. (Fig. 4, A and B). Three males emerged from the pupae on May 10, and a male and a female on May 13. Several larvae and pupae were also collected in a somewhat grass-grown, pebbly-bottomed rill (S.R.S. 1), near Hull, Que., on May 19. From these, seven females emerged on May 21, and 23. The temperature of the three streams ranged from 55° to 62° F.

Distribution.—S. mutatum has a wide distribution in North America. Malloch (29, p. 20) described the species from a female taken at Glassboro, New Jersey. He also recorded it from localities in Illinois, Missouri, Washington, British Columbia and Alaska. Dyar and Shannon (5, p. 17) added Virginia, Maryland and Indiana. I have specimens from the following localities. *Quebec:* Hemmingford, May 15 and July 25, 1928 (G. H. Ham-

mond); Montebello, May 21, 1930 (N. J. Atkinson); Pink's Lake, near Hull, June 5, 1931 (C. R. Twinn), also reared females from near Hull, May 21 and 23, 1935. *Ontario:* Niagara Glen, June 23, 1926 (G. S. Walley); near Carleton Place, reared males and females, May 10 and 13, 1935 (C. R. Twinn).

Simulium (Eusimulium) lascivum N. SP.

Female.—Length, 3–4 mm.; wing, the same; integument dark-brown to black, with pollinose dusting. *Head:* front moderate, about twice as wide at vertex as at base of antennae; median furrow distinct; clypeus somewhat broader than long; front and clypeus black, covered with dull yellowish pollinosity, and short decumbent yellowish pubescence; orbital hairs black. Antenna 11-jointed, joints four to ten sub-equal, the three basal joints larger, and the apical joint more elongate, tapering to a rounded point; color dull-black, the second joint and the distal margin of the basal joint reddish; palpi black. *Thorax:* mesonotum black with a faint yellowish or grayish pollinose dusting, and fine short yellow pubescence; three rather indistinct mesonotal vittae present, the median stripe a thin straight line, lateral ones broader, somewhat sinuate. Scutellum dark-brown to black with sparse yellow pubescence and rather short black hairs; postnotum black, pollinose. Pleurae dark-brown to black posteriorly; the lower part black with whitish pollinosity; pleural tuft small, black, with a tinge of yellow. *Wings:* hairs on stem vein black; costa with numerous short black hairs mixed with minute spinules; sub-costa with a single row of hairs; radial sector shortly and indistinctly furcate, the posterior branch with a single row of hairs on the upper surface; small basal cell present; halteres light-brown. *Legs:* coxae and underside of fore trochanters black, whitish pollinose; other joints dark-brown, with fine black and yellowish pilosity; hind tibial spurs prominent; hind basitarsus about 6 × 1, and five-sevenths width of tibia; calcipala minute; length of second hind tarsus one and one-half times the width of basitarsus; pedisulcus present but shallow; claws long, slender, with a minute sub-basal tooth. *Abdomen:* black; grayish pollinose; apices of all tergites pale-brown, terminal segment almost wholly brown; basal fringe short, of fine yellowish hair; pubescence on dorsum sparse, minute, yellowish; longer and more numerous black and yellow hairs on lateral margins of dorsal plates, and on sternal plates; tergites well developed and chitinized, none greatly reduced in width; ninth tergite (viewed laterally) dorsally emarginate and caudally prolonged, the prolongation narrow, setose; sternites one and two membranous. *Genitalia* (Fig. 8, D, 3, 4): ovipositor valves as broad at base as long, tapering, extending to one-third length of ninth sternite; weakly chitinized, spiculate, inner margins strongly chitinized; tips divergent. Anal lobe quadrangular, longer than wide, length slightly exceeding width of cercus; more heavily chitinized postero-ventrally; slightly prolonged beneath cercus; strongly setose except anteriorly and apically. Cercus quadrangular, twice as wide as long, setose. Arms of genital rod widely divaricate, expanded, toothed, the expansions each reinforced with a chitinous bar.

Male.—Essentially similar to female, but smaller; antenna entirely black; hind tibia about one-fifth wider than basitarsus, both much swollen; hind basitarsus about 3.5 × 1; length of second hind tarsal joint slightly less than width of basitarsus; basal tooth on claws more prominent. *Genitalia* (Fig. 8, D, 1, 2, 5): side-piece and clasper unusually large; side-piece conical, with long setae distally; clasper almost as long as side-piece, with long setae basally and tapered, curved, terminating with a small tooth. Adminiculum similar to *mutatum*, but about twice as wide, and the basal prongs roundly expanded. Adminiculum arms with a row of small, pointed, marginal teeth.

Holotype.—Female, Rockcliffe, Ont., reared from pupa, 13. V. 35; Can. Nat. Coll.

Allotype.—Male; same data.

Paratypes.—Four males, 5 females, Rockcliffe, Ont., emerged 13. V. 35; 6 males, 7 females, Carleton Place, Ont., emerged 27. V. 35.

Pupa (Plate I, Fig. 4).—Length 4–6 mm.; respiratory tuft bush-like in shape, usually less than one-half the length of the pupa, and composed of about 30 slender filaments (counts of twelve specimens showed as few as 27 and, in one case, as many as 40; the average was 30) arranged in a number of groups branching from a short, stout, base. The cocoon is of the *Prosimulium* type, consisting of a loosely woven silk sheath, indefinite in shape.

*Notes**.—Larvae and pupae were found in great numbers in May, 1935, in a small stream at Rockcliffe, Ont., connecting McKay Lake with the Ottawa River, and also in the falls and rapids of the Mississippi River, at Carleton Place, Ont. I first collected pupae in the stream at Rockcliffe, on May 29, 1928, but did not then rear adults.

The McKay Lake stream (McL.) is about half a mile in length, and rarely exceeds several feet in width and a few inches in depth. During the summer, with the fall of the lake level, it often dries up. The bed is of clay formation, and near the source of the stream there is a heavy growth of bulrushes and grasses. When first examined on April 13, 1935, the temperature of the water was 41° F., and only a few mature overwintering larvae of another species were found. On April 26, when the temperature of the water was 56° F., immense numbers of young larvae were present on the dead grasses, leaves and other obstructions in the water, the concentration being heaviest near the source of the stream. It seems probable that they had recently hatched from eggs laid the previous season. The young larvae were pale reddish-brown in color, before immersion in alcohol, owing to patches of pigmented cells in the thorax and abdomen. The intestinal tracts showed green through the integument, indicating that the larvae were feeding on the algae which occurred in gelatinous masses on the grasses covering the stream bottom. By May 9, when the water temperature was 59° F., the majority were mature and many had pupated. The infestation had become more

* *A collection of males received in July, 1936, from Dr. Robt. Matheson, of Cornell University, taken at Cayuta Lake, N.Y., on May 21, 1935, proved to be lascivum.*

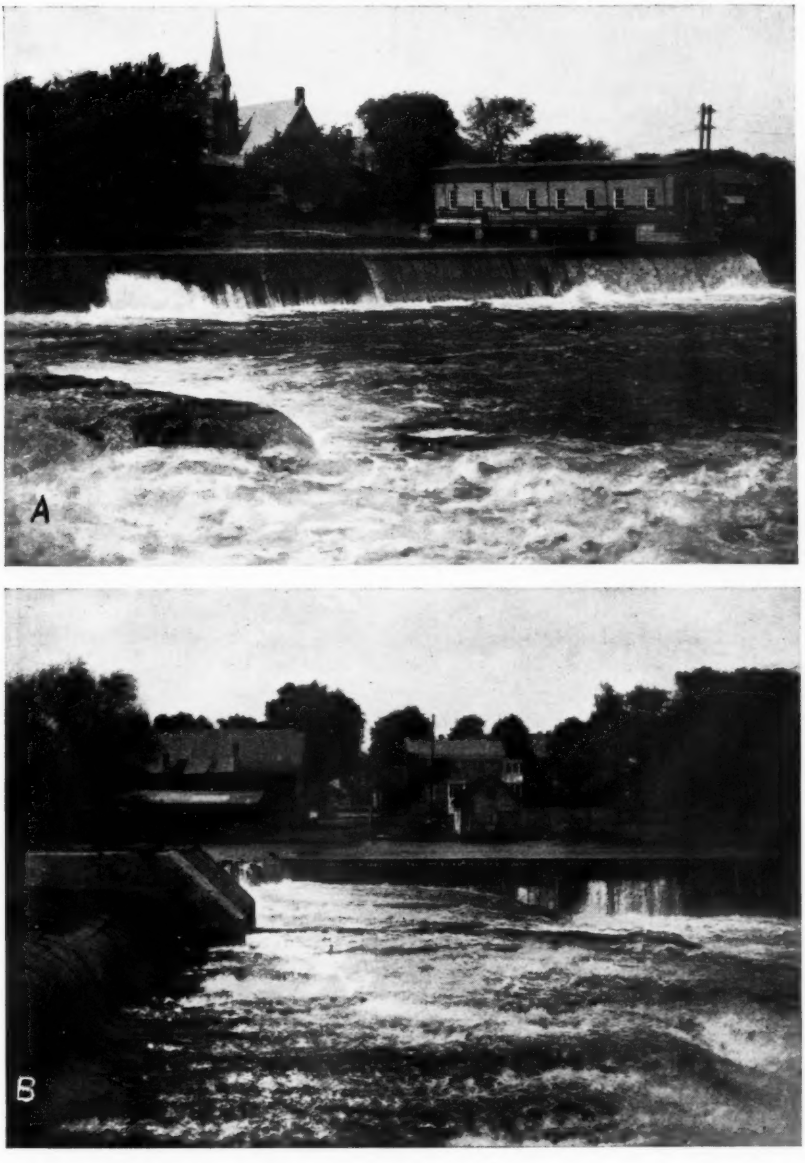


FIG. 9. *A. Mississippi river, Carleton Place, Ont.; breeding place of S. lascivum n. sp., S. pictipes Hgn., and other species. B. Another view of the above; S. ottawaense n. sp., was found to the right.*

evenly distributed throughout the course of the stream. Stones, rocks and other obstructions were thickly covered with the pupae which were hidden from casual observation by the gray-green webbing of the cocoons, and often by writhing masses of larvae. Adult flies began to emerge a few days later. By June 8, the stream was reduced to a tiny rill, and only the immature stages of *vittatum* could be found.

The Mississippi river (Fig. 9, A and B) issues from the lake of the same name above Carleton Place, Ont. Where it passes through the town it is rather shallow and swift and has a bottom of shaly rock, its passage interrupted by concrete dams. During the spring freshet the river level is high and the current strong, but often during the summer it is much diminished, and in places almost dry.

When visited on May 8, 1935, the river was high and flowing over the dam with a roar. The temperature of the water was 53° F. Examination revealed the presence of myriads of larvae on the dam oscillating in dark-green, moss-like masses in the current. The larvae were small to well-grown, but none showed the developed pupal respiratory histoblasts. When visited again on May 24, many had pupated, the pupae inconspicuous under the protective grayish covering of the cocoons. The temperature of the water was 58° F. Emergence of the flies had commenced, and numerous males were flying erratically above the water surface of the falls, or resting on the retaining walls nearby. A collection of the pupae was made and a goodly number of both sexes emerged in confinement, on May 27. It is evident that the species reaches the peak of its emergence from the Mississippi river during the latter part of May, as no trace of it was found during subsequent months either in 1935, or in previous years. On May 30, 1933, I found the adults crawling in thousands on nearby walls, many of them mating.

S. lascivum was the only species observed to mate in captivity. Numerous adults of both sexes that emerged on May 13, were actively mating in the small, damp, rearing vials, at 8 a.m. During copulation the male bends the tip of his abdomen downward and forward to connect with that of the female. Several specimens frequently clung together during this operation, tumbling about awkwardly within the confining walls of the vial. It was observed, too, that *lascivum* is not strongly attracted to light as are the adults of the other species reared.

(To be concluded in next issue.)